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(PUBLISHED QUARTERLY)

Journal of the Council for Scientific and Industrial Research.

Vol. 20. FEBRUARY, 1947. No. 1.

The Ascorbic Acid and Carotene Content of some Australian Fruits and Vegetables*

1. Introduction

From 1942 to 1945 a considerable number of ascorbic acid determinations were carried out in the laboratories of Commonwealth Food Control and the Council for Scientific and Industrial Research. These determinations were made in connexion with the supply of food to the Services, and were directed primarily to ensuring maximum retention during processing. Some determinations of carotene were made during the same period. These data may be of general interest in the field of nutrition, and are here presented.

Determinations of ascorbic acid by Commonwealth Food Control were made in every State. In addition, the Division of Food Preservation and Transport of the Commonwealth Council for Scientific and Industrial Research carried out many ascorbic acid determinations in the laboratory at Homebush, New South Wales. All the carotene determinations were made in this laboratory. Additional ascorbic acid data were obtained in Tasmania by the Division of Plant Industry, Council for Scientific and Industrial Research.

2. Procedure

Ascorbic acid was determined by the usual procedure, i.e. extraction with 3 per cent. metaphosphoric acid and titration with 2, 6-dichlorophenolindophenol. Carotene was determined by the procedure of Austin and Shipton (1944)†.

The data are presented in Tables 1 to 5. Both ascorbic acid and carotene are expressed as mg. per 100 g. (The usual procedure is to regard 1 mg. of ascorbic acid as equivalent to 20 International Units (I.U.) of vitamin C, and 1 mg. of β-carotene as equivalent to 1667 I.U. of vitamin A.) In many cases, the tables provide all the essential information, but for some products additional notes are provided in the text.

The data given in the tables represent, as far as possible, random samples of each product. In most cases the figures are for commercial material which has been received for examination or fresh material for processing experiments. It should be approximately

* Compiled from data obtained in the laboratories of Commonwealth Food Control and the Council for Scientific and Industrial Research.

† Austin, C. R., and Shipton, J. (1944).—*J. Coun. Sci. Ind. Res.* (Aust.) **17**: 115.

representative of material passing into consumption during the period of the determinations. All the processed material was analysed soon after processing. Subsequent storage often involves some loss of vitamin. Data derived from variety trials are generally excluded from this paper. Such trials usually involved only a few determinations for each of a large number of varieties, many of which are only of minor importance commercially and cannot be regarded as representative.

The tabulated data refer to the portion of the product which is normally consumed, such as the solid portion of canned foods (except juices). The individual determinations are quoted where not more than ten samples were analysed. Otherwise, the data are summarized by giving the mean and standard deviation (S.D.).

In almost all cases where the mean and standard deviation are quoted the distribution of the values was approximately normal. Among the important consequences of this are that the mean can be taken as the most representative value and that approximately 95 per cent. of the values fall in the range—Mean $\pm 2 \times$ S.D.

Cases where the distribution departed markedly from the normal form are indicated in the text. Most of the dehydrated products gave non-normal, flat-topped distribution curves. In such cases the total range would be over-estimated if normality is assumed.

Significant differences between States appear in some products. The origin of these differences is usually uncertain, as it involves many factors such as climate, soil, cultural practices, and variety. With processed foods, processing practice may have differed significantly from State to State.

The maximum percentage moisture in the dried products is as follows: cabbage, 4; carrots, 5; potatoes, 7; silver beet, 4.

3. Ascorbic Acid in Fruit Products (Tables 1, 2, and 3)

(i) *Apples.*

In a variety trial of fresh apples in Tasmania in 1944, the Sturmer variety was found to have a much higher ascorbic acid content than any other of the main varieties. Following are the figures for ascorbic acid (as mg./100g.) in whole fruit (including skin).

Alfriston—11.
Cleopatra—14.
Cox's Orange Pippin—9, 12, 12.
Crofton—11.
Delicious—9, 11.
Democrat—11, 13.
French Crab—6, 14, 15.
Granny Smith—10.
Jonathan—11.
Sturmer (17 samples)—Mean 25·5, S.D. 1·1.

The data for canned apples (mean 8·5, S.D. 4·2) are derived from a skew distribution. In this case the median is 7·9 and the range 0·5–18·6.

(ii) *Blackcurrant Products.*

Neither canned fruit nor canned pulp are normally consumed as such. Unsweetened blackcurrant is excessively sour, and hence this fruit is usually consumed as jam or syrup. The bulk of the blackcurrant pulp is processed again into jam or syrup.

(iii) *Grapefruit Juice, Canned.*

The figures do not differ significantly from State to State.

(iv) *Lemon Juice, Canned.*

The figures for New South Wales were above, and those for Queensland were below, the average for all the States.

(v) *Orange Products.*

The figures for canned orange juice show a very definite monthly variation (Table 2). There is a gradual decline from August to February in all States except Queensland. In the latter State, common oranges predominated in the varieties processed and the season practically finished at the end of September.

This decline is almost certainly due to the seasonal decline in late Valencia oranges. Except in Queensland, Navel oranges predominated before and Valencia oranges after September. This has been shown by studying the monthly variation in ascorbic acid content of fresh oranges from the Commonwealth Research Station, Griffith, New South Wales, during 1944 and 1945.

The determinations were made about the middle of each month. The figures given in Table 3 represent the average for two years. The juice from Washington Navel oranges did not vary appreciably in ascorbic acid content during the usual picking period (May to September), but the late Valencia orange juice declined steadily in ascorbic acid from August to February. The Navel juice is generally most palatable in August and the Valencia juice in October.

Figures for inner and outer rind are given in Table 3. The inner rind includes "rag," i.e. pith and segment walls which are left after pressing out the juice. The ascorbic acid content of the rind increased during the season in Navels, but decreased considerably in Valencias. The outer rind was particularly high in ascorbic acid. In both varieties, maximum ascorbic acid was approximately associated with maximum orange colour of the rind. Although not eaten fresh, the rind can contribute quite an appreciable level of ascorbic acid to orange jam and marmalade. By taking precautions to reduce loss, Huelin and Stephens (1944)* have prepared "marmalade mixture" containing 20 mg. of ascorbic acid per 100 g. almost entirely from rind and "rag."

(vi) *Pineapple Juice, Canned.*

The figures for ascorbic acid are derived mostly from the Smooth Cayenne variety. The Ripley Queen, which is mostly consumed fresh, is more than twice as rich in ascorbic acid. The mean figures

* Huelin, F. E., and Stephens, I. M. (1944).—*Aust. Food Manuf.* 13 (7): 2.

over the whole season do not give a complete picture, as there is quite an appreciable difference between the summer and winter crop.

Summer crop (Feb.-May): Mean 8·7, S.D. 1·6.

Winter crop (June-Oct.): Mean 13·1, S.D. 2·4.

4. Ascorbic Acid in Vegetable Products (Table 4)

(i) *Cabbage.*

The data for fresh cabbage given in Table 4 (mean 58·1, S.D. 13·0) are derived from a bimodal distribution with maximum about 58 and subsidiary peak about 35. These figures are for the portion usually consumed, i.e. with the outer green leaves removed. The outer portion is, however, definitely richer in ascorbic acid, as shown by the following determinations: 71, 91, 106, 108, and 133 mg./100 g.

Dried cabbage (mean 327, S.D. 110) gives a flat-topped distribution from 150 to 500 with median about 350.

(ii) *Peas, Green, Canned.*

The data from New South Wales give a flat-topped distribution with median of 11.

(iii) *Potatoes, Dried.*

The data for dried potatoes give non-normal, flat-topped distribution curves.

(iv) *Tomato Products, Canned.*

The tomato products show a slight seasonal variation, the mid-season (Feb.-March) samples being slightly higher in ascorbic acid than later (April-June) samples. The average difference is about 1 mg. per 100 g.

The figures from Victoria and Western Australia are significantly higher than those from New South Wales and South Australia. The Tasmanian figures are significantly lower than those from the other States.

5. Ascorbic Acid in Rose Hips

The analyses of rose hips are not given in the tables, which are confined to what are commonly regarded as fruit and vegetable products. Rose hips, however, are extremely high in ascorbic acid, and extracts can be added to other products to increase the ascorbic acid contents. The following data are available from three States:—

Victoria—453, 483, 495 mg./100 g.

New South Wales—517, 543, 553, 560 mg./100 g.

Tasmania—561, 652, 674, 780, 781, 816, 833 mg./100 g.

6. Carotene in Fruit and Vegetable Products (Table 5)

Carrots, Dried.—These figures should be used with caution, as they are derived by different processing techniques from a relatively small number of fresh samples.

TABLE 1.—ASCORBIC ACID IN FRUIT PRODUCTS.

Product.	State.	Number of Samples.	Ascorbic Acid (mg./100 g.).
Apples, Canned ..	Tasmania ..	31	Mean 8·5, S.D. 4·2
Blackcurrants, Canned ..	Tasmania ..	27	Mean 107·5, S.D. 13·6
Blackcurrant Pulp, Canned	Tasmania ..	217	Mean 153·4, S.D. 21·7
Gooseberries, Canned ..	Tasmania ..	33	Mean 24·0, S.D. 3·5
Grapefruit Juice, Canned*	Victoria ..	183	Mean 40·6
Grapefruit Juice, Canned*	New South Wales	131	Mean 39·6
Grapefruit Juice, Canned*	Queensland ..	21	Mean 40·4
Grapefruit Juice, Canned*	South Australia	29	Mean 39·1
Grapefruit Juice, Canned*	Total	364	Mean 40·1, S.D. 5·8
Lemon Juice, Canned* ..	Victoria ..	9	Mean 39·0
Lemon Juice, Canned* ..	New South Wales	201	Mean 42·7
Lemon Juice, Canned* ..	Queensland ..	63	Mean 34·6
Lemon Juice, Canned* ..	South Australia	31	Mean 38·8
Lemon Juice, Canned* ..	Total	304	Mean 39·2, S.D. 5·0
Loganberries, Canned ..	Tasmania ..	10	6, 9, 10, 12, 12, 13, 14, 15, 17, 21
Orange Juice, Canned* ..	Victoria ..	272	Mean 53·2, S.D. 9·7
Orange Juice, Canned* ..	New South Wales	1,000	Mean 55·4, S.D. 7·2
Orange Juice, Canned* ..	Queensland ..	205	Mean 56·0, S.D. 6·1
Orange Juice, Canned* ..	South Australia..	245	Mean 53·6, S.D. 5·0
Orange Juice, Canned* ..	Total	1,722	Mean 54·9, S.D. 7·3
Pineapple Juice, Canned*	Queensland ..	183	Mean 11·0, S.D. 3·0
Raspberries, Fresh ..	Tasmania ..	13	Mean 19·1, S.D. 6·4

* Ascorbic acid expressed as mg./100 ml.

TABLE 2.—MONTHLY VARIATION IN ASCORBIC ACID IN CANNED ORANGE JUICE.

State.	Month Canned.	Number of Samples.	Ascorbic Acid (mg./100 ml.).	
			Mean.	S.D.
Victoria	June	25	57·0	5·3
	July	21	58·2	3·6
	August	27	61·8	7·7
	September ..	21	61·5	5·8
	October	28	59·0	7·0
	November ..	36	55·8	5·5
	December ..	34	52·7	5·6
	January	40	46·3	5·2
	February ..	38	38·4	5·2
	March	2	33·4	..
New South Wales ..	June	45	54·1	5·0
	July	117	54·9	6·2
	August	128	62·5	7·4
	September ..	94	56·5	8·3
	October	134	55·4	6·8
	November ..	191	56·2	5·9
	December ..	121	55·0	5·0
	January ..	142	50·4	5·0
	February ..	28	45·9	5·0
Queensland	May	21	56·8	5·1
	June	26	50·5	6·7
	July	61	54·5	6·1
	August	46	59·0	3·7
	September ..	41	57·2	3·4
	October	9	64·7	2·3
	November ..	1	68·4	..
South Australia ..	June	29	57·9	3·4
	July	44	55·3	2·2
	August	61	55·8	2·9
	September ..	46	53·7	4·2
	October	16	54·4	4·3
	November ..	21	50·1	3·7
	December ..	16	48·3	5·0
	January	9	45·1	6·4
	February ..	3	40·1	..

TABLE 3.—MONTHLY VARIATION IN ASCORBIC ACID IN FRESH ORANGES FROM GRIFFITH, NEW SOUTH WALES.

Variety.	Month Picked.	Ascorbic Acid in—		
		Juice (mg./100 ml.)	Inner Rind (mg./100 g.).	Outer Rind. (mg./100 g.).
Washington Navel ..	April	72	64	193
	May	67	65	211
	June	69	85	278
	July	68	84	268
	August	68	89	280
	September ..	74	125	325
Late Valencia ..	August	70	83	260
	September ..	67	84	236
	October	64	59	218
	November ..	61	56	216
	December ..	55	48	183
	January	51	40	141
	February ..	48	36	119

TABLE 4.—ASCORBIC ACID IN VEGETABLE PRODUCTS.

Product.	State.	Number of Samples.	Ascorbic Acid (mg./100 g.).
Asparagus, Canned ..	New South Wales	10	10, 11, 12, 13, 14, 19, 19, 23, 23, 24
Cabbage, Fresh ..	New South Wales	77	Mean 58·1, S.D. 13·0
Cabbage, Canned ..	New South Wales	65	Mean 13·9, S.D. 5·9
Cabbage, Canned ..	Tasmania ..	99	Mean 13·2, S.D. 2·5
Cabbage, Dried ..	New South Wales	94	Mean 327, S.D. 110
Carrots, Canned ..	New South Wales	18	Mean 3·3, S.D. 1·4
Parsnips, Canned ..	New South Wales	18	Mean 3·8, S.D. 2·9
Peas, Green, Canned ..	New South Wales	38	Mean 11·4, S.D. 7·7
Peas, Green, Canned ..	Tasmania ..	38	Mean 13·4, S.D. 1·6
Potatoes, Fresh ..	Victoria ..	34	
Potatoes, Fresh ..	New South Wales	20	
Potatoes, Fresh ..	Tasmania ..	48	
Potatoes, Fresh ..	Total	102	Mean 14·4, S.D. 6·0
Potatoes, Dried ..	Victoria ..	32	
Potatoes, Dried ..	New South Wales	21	
Potatoes, Dried ..	Tasmania ..	46	
Potatoes, Dried ..	Total ..	99	Mean 39·6, S.D. 23·0

TABLE 4.—ASCORBIC ACID IN VEGETABLE PRODUCTS—*continued.*

Product.	State.	Number of Samples.	Ascorbic Acid (mg./100g.)
Silver Beet, Fresh ..	New South Wales	10	26, 26, 28, 28, 29, 31, 32, 33, 36, 50
Silver Beet, Canned ..	New South Wales	16	Mean 8·5, S.D. 5·2
Silver Beet, Dried ..	New South Wales	10	78, 82, 101, 117, 121, 125, 132, 229, 261, 343
Tomatoes, Fresh ..	Tasmania ..	29	Mean 22·3, S.D. 4·9
Tomatoes, Canned ..	Victoria ..	1,345	Mean 21·7, S.D. 3·1
Tomatoes, Canned ..	New South Wales	538	Mean 17·6, S.D. 3·7
Tomatoes, Canned ..	South Australia..	106	Mean 18·0, S.D. 2·5
Tomatoes, Canned ..	Western Australia	112	Mean 22·9, S.D. 2·9
Tomatoes, Canned ..	Tasmania ..	198	Mean 13·9, S.D. 3·1
Tomatoes, Canned ..	Total	2,299	Mean 20·1, S.D. 4·1
Tomato Juice, Canned* ..	Victoria ..	1,545	Mean 20·1, S.D. 3·7
Tomato Juice, Canned* ..	New South Wales	834	Mean 17·3, S.D. 4·0
Tomato Juice, Canned* ..	South Australia..	63	Mean 18·0, S.D. 1·9
Tomato Juice, Canned* ..	Western Australia	228	Mean 20·2, S.D. 2·4
Tomato Juice, Canned* ..	Tasmania ..	21	Mean 13·7
Tomato Juice, Canned* ..	Total	2,691	Mean 19·2, S.D. 3·9
Tomato Pulp, Canned ..	Victoria ..	1,825	Mean 21·0, S.D. 4·3
Tomato Pulp, Canned ..	New South Wales	349	Mean 18·3, S.D. 4·5
Tomato Pulp, Canned ..	South Australia..	143	Mean 14·9, S.D. 4·3
Tomato Pulp, Canned ..	Tasmania ..	209	Mean 13·8, S.D. 5·4
Tomato Pulp, Canned ..	Total	2,526	Mean 19·7, S.D. 5·1

* Ascorbic acid expressed as mg./100 ml.

TABLE 5.—CAROTENE IN FRUIT AND VEGETABLE PRODUCTS.

Product.	State.	Number of Samples.	Carotene (mg./100 g.)
Apricots, Dried ..	New South Wales	8	7·5, 7·7, 8·2, 8·8, 10·7, 10·8, 10·9, 11·0
Carrots, Fresh ..	New South Wales	13	Mean 15·07, S.D. 2·48
Carrots, Dried ..	New South Wales	81	Mean 135·0, S.D. 19·3
Silver Beet, Fresh ..	New South Wales	10	2·8, 4·6, 4·8, 5·1, 5·7, 5·7, 5·7, 5·8, 5·8, 6·2
Silver Beet, Dried ..	New South Wales	9	37·3, 41·8, 41·8, 43·7, 46·8, 51·9, 53·0, 53·5, 54·8

A Survey of Insect Pests and Details of Insecticide Trials on Army Farms in the Northern Territory

*By G. A. H. Helson, M.Sc.**

Summary.

A survey of insect pests attacking fruit and vegetable crops was made on Army farms in the Northern Territory during the "dry" season, 1945. Twenty-two insect pests and one nematode were identified attacking crops at this time. The most important pests were corn earworm, *Heliothis armigera* Hubn., centre grub, *Hellula undalis* Fabr., and cabbage moth, *Plutella maculipennis* Curtis.

Insecticidal experiments for the control of these pests were made using crude hexachlorocyclohexane (666), DDT, and synthetic cryolite. Some of these experiments could not be completed, but sufficient evidence was obtained to show that all of them were effective and that the most useful of these was DDT used as a spray or as a dust.

1. Introduction

In 1940 Army Farm Units of the Australian Army Service Corps acquired a neglected peanut farm consisting of 107 acres at Adelaide River, Northern Territory, and thus began a series of farms which eventually extended from Spinnifex, in Central Australia, to Coomallie Creek, in the Northern Territory. These farms were developed to meet the increasing demand by service personnel for fresh vegetables, fruit, and poultry which followed the progressive development of hostilities in the tropical regions of Australia and the islands to the north. A description of these farms and the crops they produced has been given by Kjar (1945).

The main farms were established at Adelaide River (130 acres), and at Katherine River (120 acres). The Katherine experiment farm was begun early in 1944, when 16 acres of virgin bush typical of the river fringe land was cleared and developed into the 1st Australian Experimental Farm by the 1st Australian Experimental Farm Platoon. This farm was established to aid agriculture in the Northern Territory, a policy which is being continued by the Council for Scientific and Industrial Research, which has acquired the farm.

The initial crops grown on the farms were not troubled by insect pests to any great extent, but as time went on, with new areas being brought under cultivation and old ones extended, the crops were attacked by endemic insects and particularly by pests introduced on fruit and vegetables imported for Service needs. In order to advise the personnel on the latest methods and insecticides for the control of insect pests, a survey was arranged, and this gave a unique opportunity of observing the pests, their effect on crops, and the methods of control in use. Many of the crops were being grown on a large scale in the Northern Territory for the first time. The survey was made during the middle of the "dry" season of 1945, at the height of the growing period, and while it is by no means complete, the survey does include all the principal pests occurring on crops which were grown at that time.

* An officer of Division of Economic Entomology.

As it is anticipated that many of the crops grown during the war will continue to be grown in the Northern Territory in the future, it seemed desirable that the results of the survey should be published for future reference. The present paper records these, and describes some field experiments carried out to test the effectiveness of DDT, crude hexachlorocyclohexane (666), and synthetic cryolite against the pests of cabbages and tomatoes, and to test the usefulness of a mixture of dichloropropane and dichloropropylene as a fumigant for the control of root-knot eelworm, *Heterodera marioni* (Cornu), which had become troublesome in seedbeds at Adelaide River.

2. Results of the Survey

The survey was made on all farms being worked in 1945 at Katherine River, Adelaide River, and Coomallie Creek. The insects which were collected and identified, and the hosts from which they were taken are set out in Tables 1, 2, and 3.

TABLE 1.—INSECTS RECORDED ATTACKING CROPS AT KATHERINE RIVER, NORTHERN TERRITORY—JULY, 1945.

Crop Attacked.	Insect Pest.	
	Scientific Name.	Common Name.
Beetroot ..	*Hellula undalis* Fabr.	Centre grub
	Hymenia recurvalis F.	Beet webworm
Cabbage ..	*Heliothis armigera* Hubn.	Corn earworm
	H. undalis	Centre grub
	Plutella maculipennis Curtis ..	Cabbage moth
	Agrotis sp.	Cutworm
French bean ..	*Agromyza phaseoli* Coq.	Bean fly
Grain sorghum ..	*H. armigera*	Corn earworm
	Aphis maidis Fitch	Corn aphis
Lablab bean ..	Unidentified immature forms only ..	Bean leaf miner
Lettuce ..	*Empoasca* sp.	Green jassid
	Orosius argentata (Evans) ..	Brown jassid
Papaw	Coccidae, unidentified	Scale insect
	Sphingidae, unidentified larval form only	Hawk moth
Potato	*Gnorimoschema operculella* (Zell.) ..	Potato moth

TABLE 1—*continued.*

Crop Attacked.	Insect Pest.	
	Scientific Name.	Common Name.
Pumpkin ..	*Epilachna 28-punctata*	Leaf-eating ladybird
	Ceratia hilaris Boisd.	Pumpkin beetle
	Rhaphidopalpa palmerstoni Blkb. ..	Pumpkin beetle
Sweet corn ..	*H. armigera*	Corn earworm
	A. maidis	Corn aphis
Sweet potato ..	*Empoasca* sp.	Green jassid
	Sphingidae, unidentified larval form only	Hawk moth
Tobacco ..	*G. operculella*	Potato moth
	H. armigera	Corn earworm
	Thrips tabaci Lind.	Tobacco thrips
	Heliothrips haemorrhoidalis Bouche ..	Greenhouse thrips
	Empoasca sp.	Green jassid
	O. argentata	Brown jassid
Tomato ..	*H. armigera*	Corn earworm
	Coccidae, unidentified	Scale insect

TABLE 2.—INSECTS RECORDED ATTACKING CROPS ON ARMY FARMS, ADELAIDE RIVER, NORTHERN TERRITORY—JULY, 1945.

Crop Attacked.	Insect Pest.	
	Scientific Name.	Common Name.
Cabbage ..	*H. undalis*	Centre grub
	H. armigera	Corn earworm
	P. maculipennis	Cabbage moth
Cucumber ..	*C. hilaris*	Pumpkin beetle
	R. palmerstoni	Pumpkin beetle
Citrus	*Aonidiella aurantii* Mask	Red scale
	Saissetia oleae Bern.	Brown scale
	Lepidosaphes beckii (Newm.) ..	Mussel scale
Papaw	*Heterodera marioni* (Cornu). ..	Root knot eelworm
Tomato ..	*H. armigera*	Corn earworm
	H. marioni	Root knot eelworm

TABLE 3.—INSECTS RECORDED ATTACKING CROPS GROWN ON ARMY FARMS AT COOMALLIE CREEK—JULY, 1945.

Crop Attacked.	Insect Pest.	
	Scientific Name.	Common Name.
Beetroot ..	*H. undalis*	Centre grub
	H. recurvalis	Beet webworm
Cucumbers ..	*C. hilaris*	Pumpkin beetle
	R. palmerstoni	Pumpkin beetle
	O. argentata (Evans)	Brown jassid
	Aphis gossypii Glover	Melon aphis
	T. tabaci	Tobacco thrips
	Haplothrips sp.	Black thrips
Tomato ..	*H. armigera*	Corn earworm
	T. tabaci	Tobacco thrips

Twenty-two insect pests and one nematode were identified attacking crops grown on the Army farms at the time of the survey. The most important insect pests at this time were corn earworm on tomato crops, and centre grub and cabbage moth on cabbage crops. A very careful search was made for aphids, and, although the hosts of many species were grown on the farms, only two species were found, the corn aphis on grain sorghum and sweet corn, and melon aphis on curcurbits.

In addition to the insects listed from Katherine River (Table 1) the immature forms of a Pentatomid bug, of a Tingid bug observed feeding on the cotton bolls, and adults of a Pyrrhocorid, *Astemma cingulatus* (Fabr.), were collected from cotton plants. An unidentified Tanypezid fly was also reared from decaying bananas. One tomato crop at a Katherine River farm was seriously affected by corn earworm which migrated from a crop of sweet corn grown on an adjacent field during the "wet" season, and harvested after the tomatoes had been transplanted. Sweet potato crops, in the same area, were seriously attacked late in the season by hawk moth and green jassids. Although the brown jassid, which transmits tobacco yellow dwarf virus disease in southern States, was present, this virus disease was not seen in tobacco crops at the time of the survey.

At Adelaide River cabbage centre grub, corn earworm, and cabbage moth heavily infested a crop of cabbages, which was saved by treatment with 2 per cent. DDT dust in July, followed by a 0·1 per cent. DDT solvent naphtha emulsion applied by a power sprayer in August. Two species of pumpkin beetles were particularly troublesome on cucumbers and melons, and their control with arsenate of lead dust was difficult. Beet webworm was a serious pest of seedling beetroot, in many cases killing the young plants. The green tree ant, *Oecophylla virescens* Fabr., while perhaps not a pest in the usual sense of the word, did select citrus trees at Adelaide River for its

nests, and the black passion bug, *Leptoglossus bidentatus* Montr., attacked a species of *Abutilon* which was being grown on wind breaks. The presence of root-knot eelworm in the seed-beds in this area was so serious that tomato seedlings were obtained from Katherine River for transplanting in the field. Papaws also suffered severely from this pest, and the plantations were very short lived and yielded poorly.

Cucumber and melon crops at Coomallie Creek, like those at Adelaide River, were seriously affected by two species of cucumber beetle, and beet webworm killed many seedling beetroot plants. Only one tomato plant infected with root-knot eelworm was found in this area. Cabbage crops were affected by centre grub and corn earworm, but the severity of attack was not as bad as at Adelaide River.

3. Insecticide Experiments

The profuse and rapid growth of vegetables under warm, tropical conditions, and the large areas involved in the Northern Territory, rendered adequate control of insect pests difficult with the usual types of insecticides. By 1944 it was apparent that there was an urgent need for some rapid mechanical means of applying insecticides to large areas and that more effective insecticides were desirable.

A power row-crop sprayer had already been developed in Canberra. This sprayer consisted of an ordinary type of power orchard sprayer with a 100-gallon vat, and was adapted to take a six-row crop spray boom to which eighteen cyclone, hollow-cone nozzles were attached in such a way that there were three nozzles to each row of plants. Two of the nozzles sprayed horizontally and slightly upwards, and the third nozzle sprayed vertically downwards on to the top of the crop. In this way a very efficient cover of the plants with the spray material was obtained. Two orchard type spray plants were available in the Northern Territory, and these were adapted in this way and were used to treat the tomato and cabbage crops on the farms in 1945. Power dusting machines could have been obtained for use on the farms but this was unnecessary because of the success of the power row-crop sprayers. Such dusts as were necessary, and all dusts in the experiments, were applied by means of a knapsack duster.

Tests had already shown that DDT was very effective against corn earworm, centre grub, and cabbage moth (Helson and Greaves, 1945). Other tests had suggested that synthetic cryolite might be useful should lead arsenate supplies become scarce, and small quantities of crude hexachlorocyclohexane (666), were also available for testing. All these materials were included in the field trials in the Northern Territory in 1945.

(i) *Trials at Katherine River.*

The trials were made at the 1st Australian Experimental Farm at Katherine on a block of 720 cabbages, and a block of 240 tomatoes planted for the purpose. The cabbages were used to test the usefulness of the insecticides against cabbage moth, corn earworm, and centre grub, and the tomatoes were used to test their efficiency against corn earworm.

In the cabbage trial the area was divided into six randomized blocks each containing six plots, with twenty plants per plot. The plants were transplanted on 23rd July, 1945, and were spaced at 2-foot intervals within the rows with 4 feet between each row. Six treatments were included in the trial:—

1 and 2 per cent. 666 " pyrophyllite " dusts;
0·5 and 1 per cent. DDT " pyrophyllite " dusts;
40 per cent. synthetic cryolite with " pyrophyllite " dust;
control.

These were applied with a knapsack duster at the rate of approximately 35 lb. to the acre. The first application was made on 14th August, and three subsequent applications followed at 10-day intervals.

At the end of September none of the plants was injured by corn earworm, but cabbage centre grub attack had begun. Accordingly each plant in the plots was rated for centre grub damage on a five-point scale, as described by Greaves (1945). These ratings are given in Table 4.

TABLE 4.—RATING FOR DAMAGE BY *H. undalis* TO CABBAGES AT KATHERINE, NORTHERN TERRITORY, AND MEAN RATING FOR DAMAGE PER TREATMENT, 30TH SEPTEMBER, 1945.

Treatment.					
1 Per cent. 666.	2 Per cent. 666.	40 Per cent. Cryolite.	1 Per cent. DDT.	0·5 Per cent. DDT.	Control.
3	0	1	0	0	31
0	0	0	13	0	38
0	0	0	0	0	21
0	0	0	0	0	33
0	0	0	0	0	22
12	24	0	0	0	29
Total 15	24	1	13	0	174
Mean rating 2·5	4·0	0·16	2·16	0	29

The sudden cessation of hostilities, and the changes in Army personnel subsequently following, prevented the experiment being carried through to harvest of the cabbage heads. However, it will be seen that all of the treatments used were effective against cabbage centre grub, that there was a positional effect at the end of the blocks in the 666 treatments, and that there was no significant difference between the treatments.

The block of 240 tomato plants in the corn earworm trial was divided into eight randomized sub-blocks, with six plots per sub-block and four plants per plot. The plants were transplanted on 17th July,

1945, and were spaced 6 feet apart within the rows with 8 feet between rows and 10 feet between each plot. The treatments were—

0·1 and 0·2 per cent. DDT solvent naphtha spray;
1 and 2 per cent. DDT "pyrophyllite" dusts;
50 per cent. synthetic cryolite "pyrophyllite" dust;
control.

The dusts were applied at approximately 35 lb. to the acre, and the sprays at approximately 80-100 gallons to the acre. The first application was made on 31st August, followed by three subsequent treatments at 10-day intervals.

Two harvests of fruit were made, the first at the end of October, and the second about fourteen days later. At harvest, a record was kept of the number of fruits infested with corn earworm and the number of sound fruit. The figures obtained are set out in Tables 5 and 6.

TABLE 5.—NUMBER OF TOMATOES INFESTED WITH *H. armigera* PER REPLICATE AT FIRST HARVEST ON 3RD OCTOBER, 1945, LEFT-HAND FIGURES, COMPARED WITH THE NUMBER OF SOUND FRUIT, RIGHT-HAND FIGURES. THE MEAN PERCENTAGE INFESTATION IS SHOWN IN THE LAST LINE OF THE TABLE.

Block Number.	Treatment.					
	0·2 Per cent. DDT	0·1 Per cent. DDT	2 Per cent. DDT dust.	1 Per cent. DDT dust.	50 Per cent. Cryolite.	Control.
1	1/40	0/48	5/65	0/36	0/43	20/66
2	0/48	0/58	0/52	0/67	0/47	3/46
3	0/39	0/49	0/50	0/30	0/50	6/71
4	1/33	0/30	0/42	0/34	0/32	8/41
5	0/44	1/57	0/34	0/38	0/35	5/37
6	0/30	0/52	0/50	0/37	0/35	1/27
7	0/40	0/49	0/64	0/61	0/43	6/51
8	0/51	0/41	0/40	3/44	0/47	5/57
Mean percentage infested ..	0·6	0·3	1·3	0·9	0·0	13·6

TABLE 6.—NUMBER OF TOMATOES INFESTED WITH *H. armigera* AT SECOND HARVEST, MIDDLE OF NOVEMBER, 1945, LEFT-HAND FIGURES, COMPARED WITH THE NUMBER OF SOUND FRUIT, RIGHT-HAND FIGURES. THE MEAN PERCENTAGE INFESTATION IS SHOWN IN THE LAST LINE OF THE TABLE.

Block Number.	Treatment.					
	0·2 Per cent. DDT	0·1 Per cent. DDT	2 Per cent. DDT dust.	1 Per cent. DDT dust.	50 Per cent. Cryolite dust.	Control.
1	0/50	5/59	5/60	0/80	0/40	10/50
2	0/47	0/60	0/48	0/46	0/53	5/60
3	0/41	0/47	0/48	0/51	0/61	10/73
4	0/46	0/34	1/43	0/47	1/41	9/44
5	0/39	7/57	0/38	0/30	2/43	2/24
6	0/21	0/54	0/67	2/15	0/55	3/40
7	0/54	0/56	0/48	0/42	0/51	5/57
8	0/46	0/54	0/47	0/47	0/51	9/71
Mean percentage infested ..	0·0	1·2	1·5	0·6	0·8	12·6

Analysis of these data is not necessary. The controls are significantly different from all other treatments, and the damage on each of the treated plots is so small that it is not possible to discriminate between the treatments.

(ii) *Adelaide River.*

At Adelaide River a small experiment with tomato plants was carried out to test the usefulness of a mixture of dichloropropane and dichloropropylene* as a fumigant against root-knot nematode, *Heterodera marioni*. In July, 160 tomato plants were transplanted in soil which had been infested with eelworm the season before. The plants were set out on a 6 × 3 Latin square design with eighteen plots each 12 × 24 ft. There were nine plants to each plot, planted 4 feet apart within the rows and 8 feet between each row. The fumigation of the plots was carried out ten days before sowing the seed, using a hand injector to apply the fumigant to a depth of 6 inches at the rate of 200 lb. to the acre. There were three treatments—

(1) Fumigation of seedbed and plot;

(2) fumigation of seedbed only and transplanting into an untreated plot;

(3) no fumigation of either seedbed or plot.

The sudden cessation of hostilities immediately affected the experiment, which also could not be carried to completion. However, in September every plant was lifted and its roots examined and rated for eelworm by the method described by Stark *et al.* (1944). At this time it was too early to obtain satisfactory results, but the observations showed that there was less eelworm attack on the roots of plants taken from the fumigated seedbed and plot and the fumigated seedbed only, suggesting that the fumigant was having a beneficial effect.

4. Acknowledgment

I wish to thank the Department of the Army and all ranks of the Australian Army Service Corps, Farm Companies, who made the survey possible, co-operated in the field experiments, and supplied transport and accommodation in the Northern Territory.

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* D–D.

Investigations on the Control of Oriental Peach Moth, *Cydia molesta* Busck., in the Goulburn Valley, Victoria

*By G. A. H. Helson, M.Sc.**

Summary.

Six species of parasites of the Oriental peach moth, *Cydia molesta* Busck., were introduced into the Goulburn Valley, Victoria, from the United States of America between 1935 and 1939, and 14,195 parasites of all species were released up to 1940, after which there were no further liberations. Three of the species released were recovered from field collections, but two of these have not been recovered since 1938 and it must be presumed that these two have failed to become established. There were 964 recoveries made of the other species, *Macrocentrus ancylivorus* Rohr., over a widely dispersed area during the period 1935 to 1940, but only four of these were from overwintering parasites. The number of recoveries decreased sharply after liberations ceased, and as no further recoveries were made after the 1939-40 season, it is unlikely that this species has succeeded in establishing itself either. Laboratory observations over a number of years suggest that this failure may be due to the long, warm autumns and lack of alternative hosts on which the parasite might overwinter.

Recent field experiments show that useful control of *C. molesta* can be achieved in the fruit of late canning peaches by two applications of a spray containing 0·1 per cent. DDT, the first applied six weeks and the second three weeks before harvest.

Earlier reports on the Oriental peach moth, *Cydia molesta* Busck., in the Goulburn Valley, Victoria, have been published by Gay (1935) and Helson (1939). Up to the time of the second report no satisfactory method of chemical control had been found, and thereafter, the emphasis was placed on biological control. The work was discontinued in 1941 because of the greater urgency of other horticultural problems associated with the war. It reopened in 1945, when sufficient DDT became available for a small field trial, and was continued in 1946.

The present paper gives details of the introduction, liberation, and recovery of parasites, for the most part since 1938, and the results of recent field trials with DDT.

1. Attempts at Biological Control

(i) *Introduction of the Parasites.*

Field recoveries of *Macrocentrus ancylivorus* Rohr., up to the end of the 1937-38 season, had suggested that this was the most promising of five introduced parasites (Helson, 1939), and that it was capable of becoming established during the summer and autumn months. It was not known, at this time, whether the insect could overwinter in the Goulburn Valley. Additional introductions of this parasite were made from New Jersey in the spring of 1938-39, and again in 1939-40, together with three others, *Macrocentrus delicatus* Cress., introduced for the first time from Southern Ohio, *Inareolata molestae* Uch., which had been introduced into New Jersey from Japan and Korea, and *Glypta rufiscutellaris* Cress. The material was received in four shipments, two in each season. The numbers of peach moth cocoons exposed to parasites in America and received in Australia in these shipments, together with the number of parasites which emerged, are presented in Table 1.

* An officer of the Division of Economic Entomology.

TABLE 1.—NUMBER OF ORIENTAL PEACH MOTH COCOONS EXPOSED TO PARASITES AND RECEIVED FROM THE U.S.A., AND THE NUMBER OF PARASITES WHICH EMERGED FROM THEM.

Number of Shipment.	Date of Receipt.	Total Number Moth Cocoons.	Number of Parasites which Emerged			
			M.ancylivorus.	*M.delicatus.*	*I.molestae.*	*G.rufiscutellaris.*
5	23rd Sept., 1938	21,448	1,076	196	113	..
6	28th Nov., 1938	20,051	3,224	191	..	..
7	28th Nov., 1939	20,000	1,707	..	..	..
8	22nd Nov., 1939	40,000	3,387	..	..	34
Total number of parasites which emerged			9,394	387	113	34

Shipments 6 and 7 were delayed in transit, taking 67 and 97 days respectively to arrive from New York, as against the average of 50 days. Nevertheless, all arrived in good condition, and in time to enable liberations to coincide with a maximum abundance of the moth larvae in the field. Thus the parasites had every opportunity of becoming established.

Table 2 shows the total number of parasites of all species which have been liberated since 1935. These liberations were made in badly infested orchards throughout the Shepparton and Ardmona districts (Fig. 1).

The material of *Bassus diversus* Muesb. liberated in 1939 was derived from a laboratory stock, the progeny of earlier introductions.

TABLE 2.—TOTAL NUMBER OF PARASITES OF ALL SPECIES LIBERATED IN THE GOULBURN VALLEY, VICTORIA, FROM 1935 TO 1940.

Species.	Season of Liberation.	Localities.	Number Liberated.			Total Number of Each Species.
			Male.	Female.	Total.	
Macrocentrus ancylivorus Rohr.	1935–36	1 and 2 ..	25	37	62	..
	1936–37	2, 7, 8, and 9	108	128	236	..
	1937–38	1, 2, 5, 6, 7, and 13	1,435	1,489	2,924	..
	1938–39	13.. ..	2,024	1,388	3,412	..
	1939–40	1, 2, 3, 5, 6, 7, 8, 10, 11, 13, 14, 15, 16, 17, 18, and 19*	2,606	2,446	5,052	..
	1940–41	Bamawm Extension	20	20	40	11,726
Glypta rufiscutellaris Cress.	1935–36	1	15	26	41	..
	1936–37	3, 8, and 12	175	203	378	..
	1937–38	3, 4, 6, and 10	332	398	730	1,149
Bassus diversus Muesb. ..	1937–38	6	7	791	798	..
	1938–39	5 and 12 ..	..	45	45	..
	1939–40	13.. ..	..	102	102	945
Inareolata molestae Uch. ..	1937–38	4 and 6 ..	9	33	42	..
	1939–40	13.. ..	13	23	36	78
Ascogaster carpocapsae Vier.	1937–38	6	..	..	164	164
M. delicatus Cress. ..	1938—39	13.. ..	69	64	133	133
Total number of all species						14,195

*Locality 19 is not shown in Fig. 1; it is situated at Kyabram, approximately 20 miles north-west from the nearest point of liberation in Ardmona.

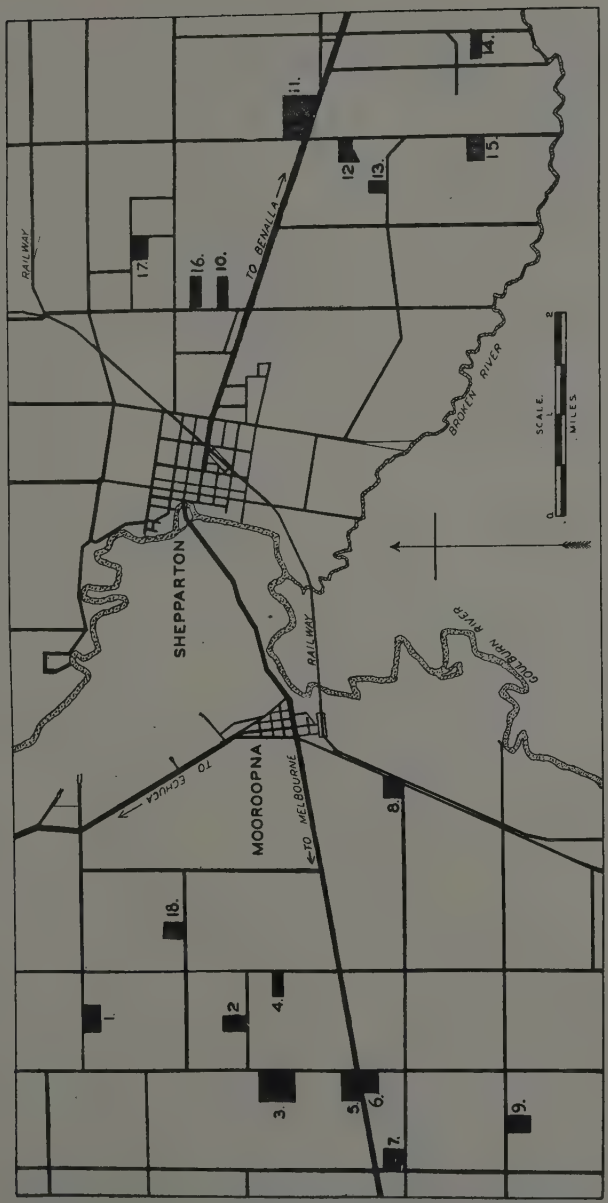

FIG. 1.—Map of Ardmona and Shepparton districts showing the orchards where parasites have been liberated since 1935.

(ii) *Recovery of the Parasites.*

Three of the five species of parasites released prior to 1938, *M. ancylivorus, B. diversus,* and *G. rufiscutellaris,* were recovered from field collections made from 1936 to 1938 (Helson, 1939), but since then no further recoveries have been made of the latter two species, notwithstanding the further liberation of *B. diversus* in 1939. No recoveries of *Ascogaster carpocapsae* Vier., *M. delicatus,* or *I. molestae* have been made at any time.

Additional recoveries of *M. ancylivorus* were made in the spring of 1938-39, when four parasites emerged from overwintering cocoons collected at localities 5 and 6 the previous autumn and stored in the laboratory during the winter. More were recovered later from peach moth larvae of the same season (Table 3). The recoveries were much lower than in the previous season, and were not made until after further liberations in December. The low numbers may be accounted for by the lack of twig infestation and the extremely hot weather in January and February.

TABLE 3.—NUMBER OF *M. ancylivorus* RECOVERED FROM LIBERATION SITES IN 1938-39.

Date Collected.	Locality.	Number of Moth Larvae Collected.	Number of Parasites Recovered
October, 1938	5	12	..
	6	30	..
November, 1938	3	295	..
	6	20	..
	8	72	..
December, 1938	3	284	..
	5	10	..
	6	300	..
	7	87	..
	13	34	..
January, 1939	3	428	2
	5	4	..
	6	218	..
	7	113	1
	8	7	1
	13	236	..
February, 1939	3	241	3
	6	241	3
	7	30	..
	13	41	..
March, 1939	6	10	..
	13	12	..
Total		2,726	10

In 1939-40 no *M. ancylivorus* were bred from overwintering larvae collected late the preceding autumn, but a laboratory colony of the parasites overwintered, although the mortality was high. Table 4 summarizes the recovery of parasites later in the season. Greater

numbers of *M. ancylivorus* were recovered than in the preceding season, and in addition small numbers of an *Inareolata* distinct from *I. molestae* appeared in the collections. This species is either a native, or was introduced accidentally prior to the commencement of the present investigation. The seven *M. ancylivorus* (all males) recovered from locality 3 in December were bred from infested twigs collected the previous month. They emerged twelve months after the last liberation (of 115 females) had been made at this point in December 1938, and probably belonged to the fourth generation bred in the field. This recovery shows that at least some of the individuals of this species withstood the heat waves of the preceding summer, and then overwintered successfully in the field on Oriental peach moth.

TABLE 4.—NUMBER OF PARASITES RECOVERED FROM LIBERATION SITES IN 1939-40.

Date Emerged.	Locality.	Number of Moth Larvae. Collected.	*M. ancylivorus.*	*Inareolata* sp.
December, 1939	3	713	7	15
	6	289	..	3
	10	140	..	1
	13	97	..	1
January, 1940	3	336	11	2
	6	104	12	1
	7	62	..	..
	8	7	..	..
	10	177	..	1
	12	13	..	..
	13	55	3	5
February–March, 1940 ..	3	328	16	3
	6	371	53	4
	7	93	1	1
	8	24	1	1
	10	178	15	2
	13	61	27	2
	16	54	9	..
Total		3,102	155	42

No parasites emerged in the spring of 1940-41 from cocoons collected at the end of the previous season, and of 200 overwintering cocoons of laboratory-bred *M. ancylivorus* only 54 emerged. During the remainder of the 1940-41 season 3,828 moth larvae, collected from infested tips at all liberation sites, yielded only one *M. ancylivorus* from a collection made at locality 6 in October 1940. This was the last recovery of an introduced parasite, although field surveys were made each December for the next three years in the districts where releases had been made.

(iii) *Discussion.*

Thus a total of 14,195 parasites, including 11,726 *M. ancylivorus* was liberated since 1935; and 964 were recovered. However, it is clear from the tables that almost all the recoveries closely followed

the releases. Only four parasites were bred from overwintering cocoons, although seven field recoveries of first generation *M. ancylivorus* in 1939, twelve months after the last liberation at this site, were undoubtedly the progeny of small numbers of this species which had overwintered and begun breeding in the spring. As there has been no evidence of the presence of any introduced parasite since 1941, it is unlikely that any of them succeeded in establishing themselves.

The percentage infestation of peaches brought to canning factories during the period covered by the liberations ranged from 4 to 50 per cent., and during the years of heaviest liberations stood at about 20 per cent., so that lack of host larvae could hardly have contributed to the failure of the parasites to establish themselves. On the other hand, three years' observations revealed that the long warm autumns caused a high percentage of *M. ancylivorus* to emerge in May and June each year, when no hosts were available. Thus there was a high mortality of parasites that ought to have overwintered. There was also a high mortality in overwintering parasites. In addition there was an absence of such alternative hosts as *Ancylis comptana* Froehl., which is present in the United States, the larvae of which provide hosts in the autumn and greatly assist *M. ancylivorus* to overwinter.

2. Chemical Control

Of 44 insecticides previously tested in the laboratory, the only one which had shown any promise was a mixture of white oil, nicotine sulphate, and bentonite (Helson, 1939). However, as the field tests with this mixture gave an unsatisfactory control, the investigation was suspended at the end of the 1937-38 season. In 1944-45, when a quantity of DDT was made available for experimental purposes, a small field test was planned to determine whether this material was of any value in the control of Oriental peach moth.

The experiment was made in Ardmona, Victoria, on a block of 169 young Pullar Cling peaches (a late canning variety), which were just coming into bearing and were subject to moderate tip infestation by Oriental peach moth. Thirty-six trees were selected on a randomized block design for two treatments, sprayed and unsprayed, each experimental tree being surrounded by buffer trees. Two applications of 0·1 per cent. DDT–solvent naphtha emulsion (Helson and Greaves, 1945) were given in 1945, and "Rucide," a commercial water-soluble DDT preparation, was used at the same concentration in 1946. The applications were made late in the season with the object of protecting the fruit from attack, the first on February 6 in both 1945 and 1946, and the second on February 21 in 1945 and on February 28 in 1946. Approximately two gallons per tree were applied in 1945 and three gallons per tree in 1946, at a pressure of 350 lb. per square inch. In 1946 heavy autumn winds caused some of the fruit to drop, but all such fruit was examined for infestation and the figures included in the record.

In the 1945 experiment, the fruit was harvested on March 3. Details of this harvest are presented in Table 5. The difference between treatments is significant at the 0·1 per cent. level.

TABLE 5.—RESULTS OF SPRAY TRIAL USING 0·1 PER CENT. DDT–SOLVENT NAPHTHA EMULSION FOR THE CONTROL OF ORIENTAL PEACH MOTH IN ARDMONA, VICTORIA, 1945.

	Treated Trees.	Untreated Trees.
Number of sound fruit	1,949	1,659
Number of moth-infested fruit ..	73	116
Total number of fruit ..	2,022	1,775
Percentage infestation ..	3·6	6·5

It will be seen that the two treatments of 0·1 per cent. DDT protected the fruit to an appreciable extent. Analysis of the fruit at harvest showed that there was a DDT residue of approximately 9 p.p.m.* A portion of the sprayed fruit was canned in the normal way, and an analysis of the syrup and fruit after canning failed to show any trace of DDT. Thus two applications of 0·1 per cent. DDT., the first six weeks and the second three weeks before harvest, did not produce a DDT residue in excess of that permitted by Health Regulations (10 p.p.m.), and no DDT was carried through the canning process into the manufactured product.

The harvest in 1946 was on March 26. The results are shown in Table 6. The difference between treatments is significant at the 0·1 per cent. level.

TABLE 6.—RESULTS OF SPRAY TRIALS USING 0·1 PER CENT. DDT IN THE FORM OF "RUCIDE" FOR THE CONTROL OF ORIENTAL PEACH MOTH IN ARDMONA, VICTORIA, 1946.

	Treated Trees.	Untreated Trees.
Number of sound fruit	2,752	2,644
Number of moth-infested fruit ..	78	262
Total number of fruit ..	2,830	2,906
Percentage infestation ..	2·75	9·0

Infestation of the fruit was again light, and showed a slight increase over the preceding season, but again useful reduction of infestation was obtained by the application of two late sprays to the fruit.

* The DDT analyses were made by Mr. R. F. Powning of the Division of Economic Entomology.

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The Use of DDT for the Control of the Buffalo Fly (*Siphona exigua* (de Meijere))

*By K. R. Norris, M.Sc.**

Summary.

Experiments on the protection of cattle against the buffalo fly (*Siphona exigua* (de Meijere)) by the use of preparations containing DDT are described. The spraying of only half the cattle in a herd results in the virtual elimination of flies from the untreated beasts. It is unnecessary to spray the entire body surface of the animals to bring about control of the flies, spraying on a patch over the shoulders being sufficient. When all the cattle in a herd are thoroughly sprayed over the shoulders with emulsions containing 4 per cent. DDT, or with DDT suspensions prepared from 1 per cent. Rucide (see page 28) they remain free of buffalo flies for approximately two weeks, after which there is a gradual increase in the fly population, usually necessitating spraying again at three weeks. As this period generally coincides with the intervals between dippings for cattle tick control, the two treatments may be applied in the course of the same muster.

Milking cows may be kept relatively free of buffalo flies by lightly spraying them with kerosene solutions of DDT. To avoid skin injury such sprays are applied as a fine mist from an ordinary household "Flit gun," which leaves a small, superficial deposit of DDT of low persistency. However, the daily handling of milkers permits treatment as often as necessary.

Large numbers of cattle, dipped or sprayed over the entire body surface with DDT preparations for the control of the cattle tick remained virtually free of buffalo flies for at least five weeks. It is suggested that the treatment resulted in the complete elimination of the fly from the large area on which the cattle grazed, so that reinfestation could only occur by the infiltration of flies from the surrounding areas. On small properties reinfestation is generally rapid, even if the protective period of the spray outlasts the life cycle of the fly.

Some factors influencing the persistency of DDT on cattle are discussed. Up to a point, persistency of emulsions and solutions varies with the concentration of DDT in the spray. The loss of DDT faster from cattle than from inanimate surfaces is considered to be due largely to rubbing and licking by the beasts, whilst the direct influence of rain and insolation in the removal of DDT is not considered of prime importance.

1. Introduction

In a previous paper (Norris, 1946) the testing of traps for the control of the buffalo fly on dairy cattle was described. The present publication is an account of experiments on the control of the fly on dairy and beef cattle by the use of DDT preparations. This material proved to have such outstanding qualities for use against the buffalo fly that attention was concentrated on its testing to the virtual exclusion of all other insecticides. The important attributes of DDT are that a buffalo fly alighting on a deposit is killed by the small quantity that it picks up on its appendages, and that sufficient quantities persist for considerable periods on treated surfaces to kill buffalo flies alighting there. The spraying of cattle with DDT preparations therefore has unique advantages for the control of the buffalo fly, which, in areas devoid of the water buffalo, is practically specific to

* An officer of the Division of Economic Entomology.

cattle, the flies spending almost their entire lifetime on the skin of the host. Although it has been found that persistency on living cattle is not as great as on inanimate surfaces, DDT is so effective against the buffalo fly that its use is now freely advocated as a practical and economical method of controlling this pest. The work described in this paper was carried out principally at Malanda, North Queensland. Notes on certain aspects of it have already been published by Legg (1945), Belschner (1946), and Roberts (1946).

2. Methods of Measuring Persistency of DDT on Cattle

The following are some possible methods of investigating the persistency of deposits of DDT on cattle:

(i) *Chemical Analysis of Extracts from Hair Clippings.*

The disadvantage of this method is that samples must be large to permit an accurate analysis for p,p′–DDT, particularly when only low concentrations are present. Both this and the succeeding method (ii) are useful for the comparison of the persistency of various preparations.

(ii) *Bioassay Tests of Clipped Hair Samples, Using the Buffalo Fly as the Test Insect.*

Quite small samples are sufficient for the performance of such tests, and testing is a relatively simple matter. The method adopted is as follows:

The samples of hair are spread out under petri dishes on paper squares glued to a wooden baseboard. The baseboard and paper are perforated by 1-inch holes directly below each petri dish. Flies are netted from untreated cattle, and, taking advantage of their strong attraction to light, transferred as soon as possible after capture into the petri dishes from beneath. The holes in the baseboard are then plugged with clean cotton wool, and the boards carrying the petri dishes placed under a strong light to activate the flies. DDT does not kill flies immediately on contact. The earliest detectable symptom is restlessness, and "excited" behaviour. A period of increasing incoordination of the legs follows, until finally the fly is unable to stand, but lies kicking or buzzing on its back or side. After the loss of the power of locomotion, the vigour of the movement of the appendages gradually decreases, and the final trace of life is the twitching of the terminal segments of the tarsi. The greater the concentration of the DDT on the surface on which the fly crawls, the more rapidly do these symptoms succeed one another, so that, by assigning ratings to the different recognizable stages of the paralysis (unaffected, slightly affected, strongly affected but still able to walk, unable to walk but still vigorously moving, almost immobile, and apparently dead), a comparison may be made of the relative concentration of DDT on different samples.

Disadvantages of this method are that it is not possible to obtain a "standard" buffalo fly comparable with the "standard" housefly of the Peet-Grady test, and that under conditions prevailing on a field station, experiments cannot be carried out under conditions of constant temperature and humidity; but in spite of these drawbacks useful information may be obtained.

(iii) *Insectary Tests.*

The treated beast may be enclosed in a gauze insectary, and observations made on the survival of buffalo flies liberated inside the enclosure. Disadvantages of this method are the small number of beasts that may be handled in any one experiment, and the strong possibility that the insectary may become contaminated with DDT through the contact of cattle with the rails, and the shedding of DDT on to the floor. Also buffalo flies sometimes tend to leave a beast in an insectary, and rest on the gauze.

(iv) *Study of the Trend of the Fly Population on a Herd Following Treatment with DDT.*

DDT is not a repellent, and the rate at which it affects flies varies as the concentration on the surface on which the flies alight. When a herd of cattle is treated with a DDT preparation, all the flies present at the time of spraying are eliminated. Those flies (emerging from pupae in the pasture, or migrating from cattle outside of it) which first attempt to reinfest the treated cattle are affected by DDT so rapidly that they are "knocked down" soon after alighting on the hides. Thus the infestation visible at any time shortly after spraying is practically nil. As the concentration of the DDT on the hides is reduced, the flies reinfesting the cattle are able to survive for longer periods, and so a gradual increase in population results, even while some DDT remains on the hides. Some of the important factors affecting the rate of reinfestation of cattle after they have been freed of flies are as follows:

(*a*) Natural variation of the buffalo fly population with seasonal conditions and biological factors. On the Atherton Tableland the fly population is at its peak in January and February, when reinfestation is rapid once a DDT spray has worn off. On the other hand, in July and August, when the fly population is at a low level, reinfestation is very slow, even if temperatures are temporarily favourable.

(*b*) Direct effect of weather on the activity of the flies, and hence on the rate of infiltration from untreated to treated areas. Cool conditions slow up the activity of the fly, and hence tend to retard reinfestation, even if not immediately reducing the numbers of the flies.

(*c*) Size of property on which the treated stock graze. The average area of dairies on the Atherton Tableland is only about 150 acres, and so very rapid reinfestation is likely to occur if surrounding properties carry untreated cattle. On the other hand a cattle station many square miles in area would be subject to only slow reinfestation from outside the boundaries.

As method (iv) provides information directly in terms of fly population, as is required from the point of view of the practical problem, it has been most employed, though supplemented at times by other tests, particularly bioassays.

3. Effect on the Population of *Siphona exigua* of Treating Cattle with DDT Preparations

DDT has been found to be highly effective against the cattle tick (*Boophilus australis*) which is an important pest throughout most of the area of distribution of the buffalo fly in Queensland. The possibility of DDT coming into general use for cattle tick control has an important bearing on the buffalo fly problem. As will be described below, it is unnecessary to spray the entire body surface of a herd of cattle to control the buffalo fly. On the other hand, complete coverage of the body of a beast is necessary for tick control, so that if DDT be correctly employed against the tick, the buffalo fly population is automatically eliminated. Use of DDT primarily for the control of the buffalo fly therefore involves different treatment from its employment primarily for the control of the tick. The two methods will be dealt with separately.

(i) *Use of DDT Primarily for Buffalo Fly Control.*

In spraying for buffalo fly control, two methods may be adopted. The hides of the cattle may be saturated with sprays of DDT, leaving a deposit of considerable persistency which will afford lasting protection against the fly, or else they may be sprayed fairly frequently with a light-mist spray of low persistency. Both methods have their uses, though the former is by far the more widely applicable.

(*a*) *Use of Saturating Sprays to Obtain Prolonged Persistency.*

As will be shown in a later section, persistency of DDT on cattle is dependent partly on the initial dose. Thus a heavy spraying, saturating the hair right to the skin surface, is the most effective way of applying any one type of spray. For use in this manner, sprays must be harmless to the skin of cattle. In this research early experiments were carried out with potentially harmful kerosene sprays, and are described hereunder merely for purposes of illustration, without suggesting that the sprays should be used nowadays for practical purposes in the manner described.

(1) *Preparations employed.*—The first experiments were carried out with straight solutions of DDT, principally in kerosene. As soon as suitable emulsions had been devised, the use of solutions was discontinued, because of the likelihood of injury to the cattle. Desquamation, particularly of the neck, was noted on a number of cattle sprayed with kerosene solution, and one herd showed evidence of loss of control of body temperature, as described by Freeborn *et al.* (1934). Emulsions tested were only those likely to be produced in quantity in Australia, the most important being power kerosene emulsion, solvent naphtha 90/190 emulsion, and *Eucalyptus dives* type oil emulsion, using "Wetsit" as the emulsifying agent (see Hackman, 1946). All proved satisfactory, and there were no indications of injury to the skin of cattle from their use. No outstanding differences in persistency between the different solutions and emulsions have been noted.

Towards the end of the phase of the research with which this paper deals, Messrs. Taubmans' "Rucide" was made available for study. This is a paste containing 50 per cent. by weight of p,p'–DDT and also a "solubilizer." The paste is melted until a clear liquid is formed, at a temperature in excess of 100°C. The melt is then poured

into soft or softened water, which is vigorously stirred during the pouring, a suspension of fine particles of DDT resulting. This preparation has considerable stability, and is apparently completely harmless to the skin of cattle.

(2) *Equipment employed.*—Large, continuous-spraying, hand atomizers were employed, also knapsack sprays to which several yards of hose had been fitted to enable one man to operate the nozzle, while another carried and operated the reservoir. For the small user such appliances are probably quite satisfactory, but for large-scale treatment of cattle with the object of controlling the buffalo fly, a motor-driven pump of some type would be desirable.

(3) *Results of experiments.*—The following experiments were carried out on dairy cattle at Malanda, North Queensland, in 1944. Continuous-spray, hand atomizers were employed to apply 4 per cent. DDT in lighting kerosene, so that the hair of the treated area was thoroughly saturated, without run-off. Although this preparation would not now be used in experiments, the results obtained in the control of the fly population serve to illustrate the development of the principles for the use of DDT against the fly.

(i) On February 8, 1944 a herd of 28 cows, 10 calves, and 1 bull were sprayed on the neck, back, and sides. Before treatment the cows bore an average of about 50 flies each. After spraying they remained practically free of flies for 8 days. From the 8th to the 15th day the mean daily infestation averaged less than a dozen flies per beast. After the 15th day the fly population rose beyond the pre-treatment level, and it was presumed that the DDT was no longer effective. The area of this property was 120 acres, and it was bounded on most sides by properties carrying untreated cattle from which the flies could migrate on to the treated cattle, surviving in increasing numbers as the DDT progressively wore off.

Eight days after treatment, 12 untreated, heavily infested calves broke into the paddock where the sprayed calves were kept. When the strange calves were removed from the paddock, considerable numbers of flies were left on the treated calves, but in less than 12 hours they were again free of flies, demonstrating that the DDT was still very active on their hides.

(ii) A herd of 48 milkers, 3 bulls, and 7 calves was treated on February 18, 1944, on the neck, back, and sides of each animal, leaving unsprayed those regions in reach of the tail in the anticipation that any flies alighting there would be driven on to the treated parts. Probably the spraying was done somewhat more heavily than in the case of experiment (i). Before spraying the cows were heavily infested, individuals carrying up to 1,000 flies, the mean being estimated at about 300 flies per beast. Practically no flies were seen on the milkers for 10 days after spraying. Until the 22nd day the highest mean number per cow at any one count was 10·5, though generally less. After the 22nd day the mean numbers ranged about 25 per beast, and did not regain their pre-spraying level before observations were discontinued on the 35th day after spraying. It is probable that the failure of the fly population to restore itself towards the end of this period was partly due to seasonal conditions. The area of the property was 167 acres, and reinfestation was possible along most of the boundaries.

An interesting comparison is provided by the history of 16 dry cows grazing on a road running past the property, which were also sprayed, but somewhat more lightly than the milkers, on February 18. In the course of their grazing along the road, these cows frequently came in close proximity to numerous untreated cattle. This fact and the lighter spraying may have been responsible for the fact that the dry cows were reinfested much earlier than the milkers. From the 8th day onwards the infestation was more or less comparable with that which reappeared on the milkers after the 22nd day.

(iii) On March 17, 1944, in a herd of 24 cows grazing on an area of 120 acres, 12 were selected as consistently carrying the heaviest infestations (mean 74 before spraying). The mean number of flies on the remaining cows was 32. The 12 most heavily infested cows and the bull (pre-spraying infestation approximately 500) were sprayed on the neck, back, and sides as far back as the hip.

All flies were immediately eliminated from the sprayed beasts. About 15 hours after spraying the mean infestation on the unsprayed milkers had dropped to 4 flies per beast, and there was less than 1 fly per untreated beast 22 hours after spraying. For 11 days after spraying the mean daily average number of flies on the sprayed milkers was less than 1 per beast. The average infestation on the untreated cattle during this period was generally less than 2 per beast (max. 4), though always in excess of the mean on the treated cattle. From the 12th to the 22nd day the numbers remained low, usually not more than 5 per beast, though generally slightly higher on treated than on untreated cattle. After the 22nd day there was a great increase in the mean numbers of flies.

This experiment demonstrated that flies move around from beast to beast frequently enough to bring about their control if only half the cattle in a small herd are treated. Laake (1946) reports similar results from experiments on the control of the horn fly (*S. irritans* (L.)) with DDT preparations. Since the performance of this test, other experiments have amply demonstrated that when cattle treated with DDT mix with untreated cattle, reduction or elimination of the flies on the untreated cattle takes place. In a further experiment the bull and every fourth cow in a herd was treated, but control was not as satisfactory as when half the number of cows was sprayed.

(iv) On April 21, 1944, a herd of 39 cows and a bull, grazing on a property 161 acres in area, were sprayed in patches about 18 inches by 12 inches on either flank, and similar areas on either side of the withers, these being the parts of the hide where the flies tend to congregate in the greatest numbers. Before spraying each cow carried an average infestation estimated at about 150–200 flies, and the bull about 2,000 flies. Until the 12th day after spraying not more than 1 fly per cow was recorded at any observation, although the bull had been observed to carry up to 9 flies during this period. The mean infestation per milker was not recorded as higher than 2 flies per observation between the 12th and the 21st days, by which time it had become doubtful whether adverse weather conditions were not hindering the reinfestation of the herd. Consequently about 400 flies netted from untreated cattle were released on the herd on the morning

of the 22nd day. There was a considerable survival of flies when the cows were brought in for the afternoon milking about 4 or 5 hours after the liberation, so it was concluded that the deposit of DDT had substantially worn off. Chemical analysis of hair samples clipped from the shoulders of cows on the 18th day after treatment showed that there was a considerable amount of DDT on the shoulders at that time (see Table 1). Infestations on untreated cows in the vicinity of the farm averaged about 200 flies per beast on the 12th day, while at 22 days untreated stock on a roadway adjoining the farm had a mean infestation of about 50 flies per head. The evidence suggests that the protection of the shoulder and flank spraying extended into the 3rd week, although the results were somewhat confused by the onset of cool weather conditions after the commencement of the test.

(v) Subsequent to the completion of this series of tests with lighting kerosene solution, numerous experiments were carried out with emulsions and Rucide, in which the shoulders only of all the cattle in a herd were sprayed, resulting in satisfactory control of the fly population. For instance, 30 head of beef cattle were sprayed over the shoulders with a 4 per cent. emulsion of DDT on November 12, 1945, at Innisfail, North Queensland. Before spraying the infestation averaged about 200 flies per beast. A fortnight later the fly population averaged only 6 flies per beast, and bioassay of hair samples showed distinct traces of DDT on the shoulders.

Evidence has been secured which suggests that DDT persists longer on the shoulders than on the flanks (see Table 1 and Section 3 (ii). The significance of such observations is that even if a beast be sprayed over the entire body, the final result, after a preliminary period of differential removal of DDT is much the same as if only the upper parts had been sprayed.

A summary of information of other miscellaneous experiments with saturating sprays of DDT in the form of emulsions and Rucide appears in Table 2. A general tendency will be noted for persistency of emulsions to vary with concentration. However, the variation is not entirely direct, as trebling the concentration (e.g., raising from 4 to 12 per cent.) does not even double the protective period.

TABLE 1.—ANALYSES OF HAIR SAMPLES FROM SHOULDERS AND FLANKS OF ANIMALS SPRAYED WITH 4 PER CENT. DDT PREPARATIONS.*

Preparation Used.	Days after Spraying.†	Situation Sampled.	Gamma DDT per gram Hair.
Kerosene emulsion ..	7	Shoulder ..	5,050
		Flank	964
Kerosene solution ..	18	Shoulder ..	1,118
		Flank	123
Kerosene solution ..	80	Shoulder ..	109
		Flank	74

* Analyses performed by Mr. R. F. Powning of the Division of Economic Entomology, by the dehydrochlorination method.

† The figures given for the cattle sampled at 80 days are at about the general level obtained when testing hair from untreated animals.

In the case of Rucide, persistency does not appear to increase with increasing concentration of spray between ½ per cent. and 3 per cent. p,p′-DDT.

TABLE 2.—RESULTS OF EXPERIMENTS WITH THE USE OF DDT EMULSIONS AND RUCIDE FOR THE PROTECTION OF CATTLE AGAINST THE BUFFALO FLY.

Concentration Percentage w/v p,p′-DDT.	Type of Emulsion.	Number of Cattle Sprayed.	Protective Period (Days).*
12 ..	*E. polybractea* + *E. dives* var. C	38	21–28
	E. dives type	81	21+
4 ..	Solvent naphtha	141	14–21
		49	15+
	Power kerosene	63	14–19
		43	11+
		48	7–14
	E. dives type	30	14–21
3	Solvent naphtha	58	12
2	Solvent naphtha	30	9–14
0·2	*E. dives* type	31	Less than 7

Rucide.

Concentration Percentage w/v p,p′-DDT.	Number of Cattle Sprayed.	Protective Period (Days).
3	81	Less than 12
	62	Less than 16
2	37	9–15
0·5	70	10–17
	40	10–17

* "Protective period" is arbitrarily chosen as the number of days elapsing after spraying before the fly population is restored to more than a dozen per beast.

(*b*) *Use of DDT Solutions as Light-mist Sprays.*

(1) *Preparations and equipment employed.*—Solutions of DDT in power kerosene have been found quite suitable for use in this method. Ordinary household atomizers are the most suitable appliances for this method of spraying, as the preparation used is potentially harmful to the skin, and stronger atomizers would deliver a spray which would actually penetrate to the skin surface.

(2) *Results of experiments.*—Solutions of different concentrations were issued to various dairymen, with instructions to use as a light-mist spray on any cows coming into the bails carrying a considerable number of flies. Inspections were made at intervals to determine the degree of control achieved.

All flies present at the time of spraying that are caught in the mist are killed, and as the spray is directed on to the places where the flies cluster in the greatest numbers, a light deposit is left where it has a residual effect on flies alighting on the cows after spraying.

The exact degree of control achieved by this method of using DDT depends on the thoroughness of the spraying programme, and the individual dairyman's conception of what constitutes an infestation of economic significance. The initial reduction of a gross infestation necessitates the spraying of most of the herd, but after that has been done it is generally sufficient to spray only a few cows every day or so to keep down the numbers of flies. Generally farmers have little trouble in keeping infestations down to a level of less than a dozen flies per beast. Observations over two seasons have indicated that a quart of 4 per cent. DDT solution in power kerosene suffices to protect a herd of 30 cows for about a month. The exact concentration of spray used is not of great importance, except that with the lower concentrations greater quantities of spray are used, with increased risk of injury to the skin of the cattle.

(ii) *Use of DDT Primarily for Cattle Tick Control.*

Observations on this aspect of the problem are confined to experiments carried out at Rannes, Central Queensland, in February 1945. This work was done in collaboration with officers of the C.S.I.R. investigating the control of the cattle tick.

(*a*) *Preparations employed.*

Taubmans' Rucide, described in an earlier section, and an emulsion of DDT in solvent naphtha were tested.

(*b*) *Equipment employed.*

For the control of ticks on cattle it is imperative that the whole of the body surface should receive a thorough drenching with the toxicant. A plunge dip which will completely immerse the body of the largest beast, or else a spray race with numerous jets to cover all aspects of a beast passing through it, must be employed. Experiments were carried out with a plunge dip on Mr. J. L. Wilson's property at Rannes, and also with a Buzacott spray race on the adjoining property of Mr. C. Guest.

(*c*) *Results of experiments.*

(1) *Dipping experiment.*—The timber-lined vat was charged with 3,000 gallons of creek water, which was softened by the addition of 1/1000 by weight of "Calgon" $(NaPO_3)x$. One per cent. w/v Rucide was added on February 8, 1946, making the p,p'-DDT content ½ per cent. w/v.

On the day the dip was charged, 1,081 head, mostly 1–2 year old Herefords, were dipped. Tagged animals were introduced into the series of animals at regular intervals for detailed study of the effect of dipping on the tick population at different stages of the run. Before dipping, the fly population on these young stock was estimated to average about 100 flies per beast, with up to 300 on some animals. Differences in the behaviour of the flies from what is usual during dipping in arsenical preparations were observed. The flies did not

work back on to the undipped beasts, there was no tendency for them to gather round the entrance to the vat (where they often rest in numbers on the rails), and very few of them followed the cattle through to the draining pen. Most flies seen in the draining pen were strongly affected with DDT, and it appeared that the Rucide exerted a slight repellent effect while the hide was still wet, as flies alighting on the cattle made only momentary contact. Probably most of the flies were knocked down or rendered incapable of normal behaviour by a mist of fine droplets caused by the plunging of the beasts. Cattle inspected several hours after dipping were standing quietly in the shade, and no flies were seen.

On February 9, 650 animals were dipped, including a considerable number of full-grown Hereford steers and bulls. The average infestation on this mob was judged to be about 300 flies per beast, with up to 2,000–3,000 in some cases. Greater numbers of flies went through to the draining pen, but this may have been merely a result of the greater population of flies. The quietness of the cattle after dipping was in marked contrast with their restless behaviour before dipping, when the flies were apparently worrying them.

The animals tagged for tick examinations were kept in a separate paddock, and were available every few days for close study in yards. No flies were seen on any of them on or before the 7th day after dipping. A total of 3 flies was seen on the tagged beasts on the 10th day after dipping, and a few more on the 14th day, though still much less than 1 fly per beast. Frequent horseback inspection throughout this period showed that in all groups of dipped animals flies were absent, irrespective of age group or sex of the cattle, although on untreated cows on the same property there was an infestation estimated to average about 300 flies per beast. Five weeks after the original dipping the cattle were brought in again for dipping, and were reported to be still almost free of flies except for small numbers on a mob which had been grazing in a paddock alongside one containing heavily infested, untreated cows.

Reinfestation tests.—A mob of 1–2 year old Herefords which were dipped on February 8th were mixed with more than half their number of heavily infested, mature cows 5 days after treatment. The cows and the heifers were forced to mix with one another in this paddock, as there was only one watering place. When drafted out the following day the cows carried infestations very much smaller than when they had been introduced to the paddock. There were no flies to be seen on the treated heifers.

A similar deliberate reinfestation was performed on the 9th day after dipping. Drafting on the 10th day still revealed no flies on the heifers. There were fewer on the cows than when introduced into the paddock, but the reduction was not so high as on the first occasion.

A third reinfestation was carried out on the 14th day after dipping. The cows were drafted out on the 15th day, when a light infestation was seen on the treated heifers. When some of these were inspected 4 or 5 hours after drafting, however, very few flies could be seen, so it is likely that DDT was still active on at least some of the beasts.

Bioassay tests.—Clippings taken from the shoulders of the tagged beasts on the 5th and 7th days, and from both the shoulders and the flanks on the 10th and 14th days after dipping, were tested for their toxicity to the buffalo fly by the method described earlier.

Strong traces of DDT were found on the hair from the shoulders of most of the beasts on the 5th and 7th days. On the 10th day after dipping there were still fairly strong traces on the shoulders, but much less DDT on the samples from the flanks of all the beasts. The samples taken on the 14th day after dipping showed some DDT on the shoulders of 4 of the 10 beasts sampled, but only weak traces of DDT on the flanks of 2 of the same 4 beasts, with none on the remainder.

The life-cycle of the fly was estimated not to exceed 10 days under the hot conditions prevailing at the time of the tests, so that it appears highly probable that the protective period of the dipping lasted long enough to kill all flies emerging from the dung on the property on which the treated cattle grazed. Thus the initial fly population was entirely eliminated, and reinfestation was left to infiltration of flies from outside the boundaries. As the area on which the treated cattle grazed was a compact block of approximately 15,000 acres, infiltration would be expected to be slow. This is an adequate explanation of the long period over which the cattle were observed to remain free of flies. The same reason has been advanced by Matthysse (1946) to account for the prolonged scarcity of horn flies on beef cattle sprayed in Florida with DDT preparations, and Peairs (1946) for the disappearance, after one treatment with DDT, of horn flies from a small herd of heifers in Virginia, which were effectively isolated from reinfestation.

(2) *Spray race experiment.*—The spray race was a Buzacott product, 36 feet in length, with rows of nozzles above and below the cattle on either side, the upper nozzles directed downwards and inwards, and the lower upwards and inwards. It was designed for continuous operation, the cattle walking from the forcing yard to the draining pen through the drenching spray.

(*a*) The first spray tested was a solvent naphtha emulsion containing 1 per cent. crude DDT (75–80 per cent. p,p′-DDT). On February 10 this was applied to 100 Australian Illawarra Shorthorn milkers, which, before spraying, were infested with about 50 flies per head. No flies were seen in the draining pen, and there was no accumulation of drowned flies in the gauze screens of the filters over the reservoir, as usually occurs when arsenical fluids are employed. During spraying operations about a dozen flies strongly affected by DDT were caught in an entomological net which was standing like a windsock downwind from the entrance to the race. Apparently the flies were caught in a mist of fine droplets at the mouth of the race, and immediately becoming affected with DDT, lost the power of directive flight, and were carried away downwind.

Cows were tagged at regular intervals during the spraying for detailed tick studies, and the tagged cows were run with the rest of the herd. The cows remained entirely free of flies for the first 9

days, after which small numbers, less than 1 per beast, could be seen, but it was reported that the infestation did not build up markedly during the 5 weeks following spraying. The dairy was 2,000 acres in area, adjoining the property on which the cattle were treated in the plunge dip, and so the failure of the flies to reappear on the cattle may be attributed to the same causes already suggested.

Bioassay tests.—Hair samples were taken from the shoulders of the milkers on the 3rd, 5th, and 8th days after spraying. There was fairly strong evidence of DDT on the shoulders of the cows on the 3rd and 5th days, but on the 8th day only one beast gave a positive test. The cows were particularly short in the coat, however, and in some cases only very small samples of hair were secured. This invalidates any comparison with the long-haired Herefords that were used in the dipping test.

(*b*) Also on February 10, 100 full-grown A.I.S. steers were sprayed with 1 per cent. Rucide ($\frac{1}{2}$ per cent. p,p′–DDT) prepared with rain water. The animals which were tagged at regular intervals during the spraying for detailed tick studies were transferred to the property where the dip was situated, and kept with the tagged Herefords from the dipping experiment. The remainder of the steers were retained on the same property as the milkers, but kept in a separate paddock.

Before spraying the steers carried an average infestation of about 100 flies per beast. The history of the fly population on both the tagged and untagged steers was the same as on the dipped animals.

Bioassay tests.—Hair samples were taken from the shoulders of the tagged steers on the 3rd and 5th days after spraying, and from both the shoulders and the flanks on the 8th and 12th days. The results of testing these with flies were comparable with those obtained for the dipped Herefords. In particular the more rapid disappearance of DDT from the flanks than from the shoulders was confirmed, as no flank samples were demonstrated to carry DDT, whereas shoulder samples from several of the beasts on the 8th and 12th days showed distinct traces of DDT. The hair of the steers was longer, on the average, than that of the cows sprayed with solvent naphtha emulsion, but not nearly as long as that of the Herefords.

4. Persistency of DDT on Cattle

When preparations of DDT are applied to inanimate surfaces, persistency in sufficient quantities to act as a contact poison to insects usually runs into months. For instance the haired surface of a piece of fresh cattle hide was sprayed with 1 per cent. DDT in alcohol in October 1943. During the week following spraying, the hide was repeatedly exposed to sunshine, and washed under a tap with an amount of water equivalent to many inches of rain, but for the rest of the period during which it was studied it was stored indoors. More than 8 months after treatment the hair was found still to be toxic to buffalo flies confined on it under a petri dish. There is an extensive literature concerning the prolonged persistency of DDT deposits on inanimate surfaces.

By contrast, the persistency of DDT on the living bovine is short, even considering the almost continuous exposure of the deposit to the effect of the elements. The persistency of DDT on cattle is known to depend to some extent on the type of preparation employed. For instance Matthysse (1946) states that deposits from suspensions are more persistent than deposits from emulsions.

The rate of application of sprays affects the persistency. Light mist-sprays of the type described on page 32 have very low persistency when compared with sprays which thoroughly drench the hide with a preparation of the same concentration of DDT. This simply amounts to a variation in the initial quantity of DDT applied to the hide (see below). Table 2 provides some evidence that persistency of emulsions is governed by the concentration of spray applied. Evidence that the same holds for solutions is provided by the following experiment:

Groups of 3 cows within the same herd were evenly sprayed with solutions of 1, 4, 8, 12, 16, and 20 per cent. w/v DDT in solvent naphtha at Malanda on May 15, 1945. As the cows from each treatment were running together, results could not be judged by fly population measurements. Instead, bioassay tests were made on hair samples taken from the shoulders of the beasts at intervals after spraying. Table 3 indicates quantitatively the relative progress of the DDT poisoning in the flies after one hour of exposure to the samples. It will be noted from the table that persistency appears to

TABLE 3.—TOXICITY TO BUFFALO FLIES OF HAIR SAMPLES FROM COWS SPRAYED WITH SOLVENT NAPHTHA SOLUTIONS OF DDT.*

Days after Spraying.	W/V Percentage DDT in Solvent Naphtha.					
	1.	4.	8.	12.	16.	20.
1	4	5	4	4	5	5
4	4	5	4	4	4	5
7	4	5	5	5	5	4
10	3	4	4	5	4	4
13	3	4	4	4	5	5
16	2	4	4	5	5	5
19	1	3	4	4	4	5
22	..	3	2	4	4	4
25	..	1	3	4	5	4
30	..	2	2	3	3	2
35	..	..	3	3	3	1
40	..	..	—	3	1	—
	..	..	—	—	—	1
	..	..	2	3	1	—
45	..	..	..	—	—	—
	..	..	..	—	1	2
	..	..	..	2	—	—
50	..	..	..	—	..	..
	..	..	..	—	..	..
	..	..	..	1	..	..
55	..	..	..	—	..	..
	..	..	..	—	..	..

*Ratings in the table illustrated the relative progress of the symptoms of DDT poisoning in the flies after one hour of continuous exposure to the samples. Up to the 35th day the samples were bulked for testing, but for the remaining four sampling days the hair from the three cows in each treatment was tested separately.

diminish after the concentration of the spray increases beyond 12 per cent. The most likely explanation of this is that the sprays caused scalding which was observed to vary with the concentration of the DDT in the spray, and that desquamation, which was only very slight with the sprays of low concentration, was particularly severe on the cattle sprayed with 16 and 20 per cent. solution. It is possible that the scabs of epithelium working out through the hair carried away a proportion of the DDT in the case of the 16 and 20 per cent. sprays.

The samples taken the day following treatment showed that the hair from the 1 per cent. treatment affected the flies somewhat more slowly than the hair from the remaining treatments. This seems to suggest that somewhere between the 1 and 4 per cent. concentration complete coverage of the hair with DDT occurs.

5. Factors Responsible for Loss of DDT from Cattle

Early in the research consideration was given to the possible factors responsible for the comparatively rapid disappearance of DDT from cattle. Suggested factors were as follows: (*a*) Rainfall, (*b*) solar radiation, (*c*) detoxification by dust or mud, (*d*) rubbing and licking by the cattle, (*e*) natural shedding of hair, (*f*) absorption into the skin and hair, (*g*) removal or destruction by skin secretions, (*h*) removal by flakes of epithelium.

Factors (a) and (b).

Peairs (1946) attributes importance to rainfall. Matthysse (1946) also considers that rainfall and sunlight are of major importance in the removal of DDT from sprayed cattle, advising spraying under the belly as well as over the back, to ensure lasting protection from horn flies. Evidence has been advanced in previous sections to show that DDT disappears more rapidly from the flanks than from the shoulders. This is inconsistent with the theory that rain and solar radiation are major factors in the removal of DDT from cattle.

To obtain some check on the effect of these factors on the rate of disappearance of DDT from cattle, two pieces of hide from a freshly killed beast were sprayed with 4 per cent. DDT in power kerosene, and two with 4 per cent. DDT in power kerosene emulsion. One half of a hide from each pair was protected from rain by covering it with a shield of celluloid, which did not, however, impede the circulation of air. The other half was left unprotected. These hides were exposed to the weather on a roof at Malanda on April 28, 1944, the other member of each pair being stored indoors as control. One month after exposure both the portion exposed to sun and rain and that exposed to the sun only, of both solution- and emulsion-treated hides were as strong in their effect on buffalo flies (confined on them under petri dishes) as the corresponding controls. Only 15 points of rain had been recorded since the date of exposure, and the days had mostly been fine and warm.

Two months of exposure produced a noticeable weakening of the DDT on the completely exposed end of both hides compared with the appropriate control. The portions protected from the rain on each hide showed a higher concentration of DDT than those exposed to both

sun and rain, but the effects on the flies were noticeably weaker than those produced by the controls. The rainfall recorded since the previous test totalled 519 points, and there had been very little sunshine.

At 3½ months these effects were somewhat accentuated, but there was still sufficient DDT on all the exposed hides to kill buffalo flies. A further 551 points of rain had been recorded since the previous tests, with a fair number of fine days.

Had similar preparations been applied to living cattle at the same time as the hides were treated, it is unlikely that even a trace of DDT would have been detected at the first examination one month after treatment, irrespective of the weather conditions to which the cattle had been subjected. Thus it appears that the effect of weather is quite insufficient to account for the rapid disappearance of DDT from living cattle.

Factor (c).

Detoxification of the DDT by dust or mud, either mechanical or chemical, may occur under certain circumstances, but DDT disappears from cattle grazing on unbroken swards of green paspalum, where both dust and mud are reduced to a minimum.

Factor (d).

Rubbing and licking by the cattle probably remove considerable quantities of DDT. The disappearance of the DDT faster from the flanks than from the shoulders may be accounted for by the animals rubbing against bushes and long grass. Whenever a beast lay down to rest, it would probably brush off some of the deposit.

Some beasts at least can reach a considerable area of the body surface with the tongue, from the butt of the tail to the base of the neck, in the course of the natural cleaning of the skin. It is not unlikely that licking, which is an exceedingly vigorous action, removes a considerable amount of DDT. In one experiment in which a DDT spray was applied to cattle in sufficient quantity to leave a white coating on the hair, the visible deposit was completely removed where the tongue had traversed the skin.

Factor (e).

Natural shedding of hair in small quantities is a continuous process (Duerden and Whitnall, 1930). At most times of the year it is insufficient to account for the rapid disappearance of DDT from cattle, though it may be a factor during the post-winter moult, which does not, however, extend over a very long period.

Factor (f).

Absorption into hair, if it occurred, would be detectable by chemical analysis of hair sampled after other methods had indicated there was no DDT left on the hide, but analyses do not point to this factor as a reason for the disappearance of DDT from cattle. Absorption into the skin is more likely to occur, but more difficult to detect.

Factor (g).

Removal or destruction by skin secretions is a factor still awaiting investigation. Kelly (1943) states that European breeds of cattle have almost lost the power of sweating. This would appear to rule out at least a mechanical effect from sweat. Little is known of the sebaceous material of cattle, but the continuous secretion of this may play a part in the removal of DDT.

Factor (h).

The mechanical effect of desquamation may be of some importance. The natural shedding of scurf would certainly remove the DDT from the immediate skin surface. However, it is doubtful whether scurf in working its way out through the hide, would scrape DDT off the hairs, though where scalding had been produced by a spray, large scabs working their way out through the hair may scrape off some DDT.

To sum up, most importance in the removal of DDT from cattle is attributed to the beasts' licking themselves, and rubbing against plants, the ground surface, etc. The effect of meteorological factors is secondary in importance. In addition there are factors associated with the skin physiology of the cattle which still await elucidation.

6. Discussion

As stated earlier in this paper, the problem of the control of the buffalo fly on cattle is closely bound up with the problem of the control of the cattle tick. Should DDT come into general use for the control of the tick, the control of the buffalo fly would be achieved automatically. In comparing the cost of using Rucide for the control of tick with that of arsenical dipping, this fact should be taken into account.

Where the use of arsenicals is continued, mustering for dipping affords a convenient opportunity for the application of the comparatively small dose of DDT required for the control of the fly. Cattle entering a dip with a wet deposit of DDT emulsion on their hides have been found by chemical analysis of hair samples to lose about 95 per cent. of the DDT in the dip.* Therefore the only practical place for spraying is in the draining pen, unless another crush is available, to which the cattle can be passed without trouble after dipping. No interference with the effectiveness of DDT sprays seems to result from spraying cattle that have only partially drained after dipping. Unfortunately in some cases draining pens are large enough to permit fairly free movement of the cattle, making it difficult for an operator to reach beasts in the centre. Better access can be had by erecting a " catwalk " of raised planks around the pen, which will enable a man to operate spraying gear over the fence, without interference to his movements by the posts or rails. Knapsack sprays with trigger-grip control of jet, and enough hose to permit one man to operate the pump while another manipulates the spraying nozzle have been found satisfactory in the comparatively small-scale experiments

* Analyses performed by Mr. R. H. Hackman of the Division of Economic Entomology.

described herein, and many graziers have successfully used these and other hand-sprays for the treatment of beef cattle after dipping. However, for really large-scale work, motor-driven pumps are essential, and attention is now being given to the selection of suitable machinery for this purpose. A simplified spray race, with draining floor, and a few permanently-fixed jets to treat the upper parts of the animals is also a practical possibility.

As mustering for tick control is availed of for the application of sprays to control the buffalo fly, the spray applied should produce satisfactory control of the fly for the period of 3 weeks which usually elapses between dippings. Matthysse (1946) states that emulsions must contain at least 2·5 per cent. DDT to afford lasting protection against the horn fly. In the research on the buffalo fly, most attention has been given to emulsions containing 4 per cent. DDT, as it was found early in the investigations that this concentration very nearly fulfilled the requirement of affording protection for the period of 3 weeks between dippings for the control of the tick. Increasing the protective period by even a week involves an inordinate increase in the concentration of the spray used. Possibly slightly lower concentrations of emulsions would prove satisfactory, but even treatment with 4 per cent. preparations sometimes permits the re-establishment of a considerable population during the third week after spraying. Rucide gives satisfactory results at 1 per cent. concentration (½ per cent. p,p′–DDT), resulting in the cattle remaining virtually free of flies for about a fortnight. Increasing the concentration of the Rucide does not appear to enhance protective periods as with emulsions. Matthysse (1946) found that no gain resulted from increasing the concentration of suspensions above 1 per cent.

For large-scale use of DDT against the buffalo fly, Rucide is unquestionably the most suitable preparation yet available. For the small owner, however, emulsions have the advantage that any fraction may be drawn from a supply of concentrate without detriment to the quality of the remainder. On the other hand the stratification of solidified Rucide requires that the whole of a batch should be melted before a portion is removed. The remelting of the bulk supply creates a risk of wastage of material.

The partial spraying (i.e., spraying over shoulders only) of cattle with 1 per cent. Rucide is the cheapest method of buffalo fly control. About 3 gallons of spray are required for one treatment of 100 head. During the course of the average buffalo fly season (usually about 5 months), approximately 7 sprayings are required. The present price of Rucide (1 lb. lots) is 8s. 6d. per lb., so that the cost of treating 100 head against buffalo fly in a typical district is about 19s. per annum.

Dairy farmers may use either traps or sprays to keep their milking cows free from buffalo flies, but partial spraying of cattle for buffalo fly control is so cheap and effective that the use of traps is no longer considered economical. The initial cost of a trap is £25–£30, which, quite apart from depreciation and maintenance, is equivalent to the cost of sufficient spray materials for the protection of 100 head (more than the usual number of cows in a milking herd) for between 20 and 30 years. Furthermore there are usually dry cows and other stock on a dairy which cannot be made to use a trap, and for the protection

of which spraying gear and DDT must be purchased irrespective of what is done for the protection of the milking herd. Partial spraying may therefore be advised as the most generally useful method of controlling the buffalo fly.

As described in Section 3 (ii) of this paper, there is good reason to believe that the larger the area of land over which simultaneous treatment of all cattle with DDT is carried out, the more effective and prolonged is the control of the buffalo fly. Thus it appears logical to conclude that the most economical and effective method of buffalo fly control in closely subdivided districts would be the simultaneous spraying with DDT preparations of all cattle over wide areas.

7. Acknowledgments

Appreciation is expressed of the cooperation afforded by farmers, too numerous to mention individually, who have assisted by making their herds available for purposes of experiments.

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The Use of DDT in Dips to Control Cattle Tick

By L. F. Hitchcock, M.Sc., and I. M. Mackerras, B.Sc., M.B., Ch.M.**

Summary.

Field experiments are reported in which good control of cattle tick (*Boophilus microplus* Canest.) was obtained with dips charged with ½ per cent. DDT in a water-miscible preparation.

Residual activity lasted between one and two weeks, during which time the cattle appeared to act as poisoned baits clearing the pastures of larval ticks.

1. Introduction

The dipping observations here reported were planned by the writers, but were carried out in various parts of Queensland by several members of the Division of Economic Entomology, namely, at Rannes, by L. F. Hitchcock, W. J. Roulston, and W. R. Horne; at Gracemere, by W. J. Roulston; at Toomba, by W. J. Roulston and R. W. Kerr; and at Innisfail, by G. J. Snowball, R. W. Kerr, A. Mills, and R. Meyers.

During the past four or five years, owners in parts of Queensland had been experiencing increasing difficulty in controlling ticks, even with fortnightly dipping in ordinary arsenical solutions, while many cattle moving south were being held up for repeated dippings at cleansing stations. It seemed evident that resistance to arsenic was spreading in the tick population, and the search for an alternative killing agent therefore became urgent. Evidence from abroad (unpublished O.S.R.D. reports) and preliminary experiments in Queensland had shown that emulsions containing DDT were efficient in killing the cattle tick (*Boophilus microplus*) in all its parasitic stages, but a stumbling block to further progress was the difficulty in obtaining a preparation which would remain stable in a dip and could be used safely on a large scale. At this stage Messrs. Taubmans Ltd., Sydney, developed a water-miscible preparation, which they registered under the name "Rucide," and which gave some promise of fulfilling requirements. Owing to the energetic co-operation of Mr. J. L. Wilson, Chairman of the Cattle Committee of the United Graziers Association of Queensland, and his willingness to risk losses of cattle to test the efficacy of DDT in dips, we were able to begin field trials much more quickly than would otherwise have been possible.

The work is not complete, but the results of the field experiments have been so good that a preliminary report is felt to be justified.

There are three separate phases in the control of cattle tick in Queensland:—

(i) Control of ticks on grazing and dairying properties. The aim is not to exterminate the ticks, but to reduce their population to a level at which the minimum of damage is caused, while permitting enough transmission of piroplasmosis for cattle to maintain their immunity.

* An officer of the Division of Economic Entomology.

(ii) Cleansing cattle for movement from infested to clean country, so that spread of infestation in Australia will be retarded.

(iii) Reclaiming infested country by a campaign of eradication.

We are concerned here only with the first of the three. Cleansing experiments are being undertaken, and the residual activity of DDT gives it obvious advantages for eradication of ticks, but neither will be considered further in the present paper.

Our thanks are especially due to Messrs. J. L. Wilson and C. McDouall (Rannes), Alister Archer (Gracemere), E. E. D. White and H. McKinnon (Toomba), and W. D. Davies and A. Stoter (Innisfail) for their co-operation and help in the field work, and to Messrs. Taubmans Ltd., Sydney, for the gift of part of the Rucide used.

2. Preliminary Experiments

Several experiments were carried out on small groups of cattle in 1944 and 1945 by one of us (L.F.H.). The cattle were mostly sprayed individually, usually with a power sprayer, and DDT emulsions were used in most experiments, though solutions were occasionally employed. Their purpose was to determine the toxicity of DDT to ticks, but they also provided guidance for the later work with Rucide, so the results may be reviewed briefly here:—

(i) Using 0·5 per cent. DDT in alcohol on artificially infested cattle, semi-engorged nymphs were found to be relatively resistant, and all other parasitic stages highly susceptible. This observation has been confirmed in later field work, the nymphs being the slowest to die, and any survivors maturing having been in the nymphal stages when dipped.

(ii) On naturally infested cattle sprayed with emulsions, 0·5 per cent. DDT gave a good kill of ticks, 1 per cent. a very good kill, and 2 per cent. practically consistently a complete kill in 68 animals tested. Protective periods, during which larval ticks failed to attach, were:—

0·5 per cent. DDT—7 days.

1 per cent. DDT—9–10 days.

2 per cent. DDT—10–12 days.

(iii) In examining the effect of season, ten animals were sprayed with 2 per cent. DDT emulsion in September, December, April, and July. The kill was practically 100 per cent., and the protective period 11–12 days at all seasons.

(iv) In a preliminary run with Rucide, spraying only one animal at each strength, the following results were obtained:—

Strength.	Kill.	Protective Period.
2 per cent. DDT	complete	15 days.
1 per cent. DDT	complete	12 days.
0·5 per cent. DDT	very good	10 days.
0·25 per cent. DDT	good	7 days.

In view of these results, and because dipping was expected to wet the cattle more efficiently than spraying, 0·5 per cent. DDT was chosen for the first dipping experiment.

Although there was no reason from the literature (unpublished O.S.R.D. reports; Orr and Mott, 1945) to expect that DDT would be toxic to cattle at the concentrations proposed, it was considered wise to carry out some experiments under Australian conditions. A well-grown beast might retain a gallon of fluid on the skin and hair, so it might conceivably absorb about 20 g. of DDT, or roughly 50 mg. per kilogram, from a single dipping in 0·5 per cent. DDT. Dipping might be monthly. Three experiments were set up, in which dosage considerably exceeded these amounts:—

(i) Two animals were given an aqueous suspension of DDT by stomach tube fortnightly; one received seven 25-g. doses in 14 weeks, the other three 50-g. doses in 6 weeks; both remained well.

(ii) One animal was given 50 g. DDT in 200 ml. eucalyptus oil and liquid paraffin *per os* fortnightly for six months, and a control received the oil mixture without DDT; both remained well.

(iii) Eighteen young Hereford steers of mean weight 548 lb. have been inuncted along the back weekly with 22·5 g. DDT in 300 ml. peanut oil. These animals were intended to be maintained on a high plane of nutrition in Queensland, while a parallel series under the care of Dr. A. W. Turner in Melbourne were to be kept on a low plane; owing to season, the nutrition of the Queensland group is only fair. The experiment is to run three years, with a group from each series killed for post-mortem examination at the end of each year. To the end of 33 weeks, no evidence of DDT poisoning has been seen.

3. Preparation of Rucide Dips

Rucide consists of 50 per cent. p,p′–DDT incorporated in a "solubilizer." It is a solid, with something of the appearance and consistency of lard, and must be melted by heat before mixing with water. The procedure is to melt the Rucide, with constant stirring, over a slow fire, pour it slowly into a drum of soft or softened water (again with vigorous stirring) to make a concentrate of from 4 to 12 per cent., and then tip the concentrate into the water in the dip. The resulting suspension is exceedingly fine and stable, almost of colloidal quality, though it does tend to settle out slowly with time.

Certain points in the use of Rucide require brief mention:—

(i) Heating must be slow and careful. Rucide melts at about 100°C., and the temperature does not rise much above that level until a certain amount of water present has been driven off in fine bubbles. Normally it forms a clear brown solution. When all the water is driven off decomposition occurs at about 150°C. The solution darkens, and will no longer mix with water (Powning,

unpublished). Local over-heating will produce the same effect in part of the material, so the need for caution is apparent.

(ii) Rucide will not mix with hard waters, and a softener must be added if ordinary soap will not lather readily in the water. We have had excellent results with "Calgon" (sodium hexametaphosphate) at the rate of 1 oz. Calgon per degree of hardness per 100 gallons of the water. Even with soft waters we have the impression that small amounts of Calgon (e.g., 1 in 10,000) improves the fineness and stability of the suspension.

(iii) The strength of the initial concentrate may be varied as desired, but should not exceed about 12 per cent. (Powning, unpublished). Thus, the contents of a 56-lb. pail may be poured into a 44-gallon drum of water, or it may be divided between two drums. Concentrates appear to remain stable for some hours, but the general practice is to have the drum at the entrance or exit of the dip and pour it in as soon as mixing is complete.

(iv) It is not necessary to be over-meticulous in cleaning out a dip preparatory to filling with Rucide. Excess debris and deposit should, of course, be removed, but there is evidence that a moderate layer of silt on the bottom is beneficial, in that it prevents caking of DDT that settles out, and ensures that it will re-disperse readily when thoroughly stirred by the first few cattle to be put through.

It is unfortunate that, up to the time of writing, we have not been able to use chemical analysis to determine the actual amount of DDT present in the dips. Consequently, the amount of Rucide to be added when topping up after use can only be calculated from volume on the assumption that the remaining fluid still contains 0·5 per cent. DDT, while the activity of the fluid can only be assessed by its actual effect on tick-infested animals. These limitations prevent us from offering collateral evidence on the results obtained; but, after all, it is the practical effect of dipping in which the grazier is interested, so we feel that the work does not lose so much by being limited to an examination of that effect.

4. The Dipping Experiments

Observation of the general effect of dipping is easy, but quantitative estimation is difficult, chiefly because the tick population cannot be determined by any method short of placing control animals in a stall and collecting the adults, as they fall, over the ensuing five weeks. Consequently, the percentage kill of ticks cannot be recorded except in very general terms. Data were collected in three categories:—

(i) The general infestation of the herd was estimated prior to dipping as light, moderate, or heavy, on the basis of numbers of ticks observable and their distribution on the body. Subsequent to dipping, surviving ticks could be

counted individually if the result was satisfactory, but the kill was usually recorded as complete, nearly complete, or incomplete.

(ii) Close examination of a sample series from the herd was made to determine the stages of development of the ticks present prior to dipping and also at various periods after dipping. These stages were classed according to Table 1 (from Hitchcock and Horne, unpublished), and the stage at dipping was calculated back for survivors after dipping by means of the same table. Results were recorded, not as numbers of ticks found, but as numbers of animals in the group on which the different stages were found.

(iii) Samples of the herd were searched for re-infestation at various periods after dipping, the results being recorded as in (ii).

TABLE 1.—STAGES OF *Boophilus microplus*.

(*Age in days from attachment.*)

	Larvae.				Nymphs.				Adults.		
	Young.	Medium Sized.	Semi-engorged.	Engorged.	Young.	Medium Sized.	Semi-engorged.	Engorged.	Young.	Medium Sized.	Engorged.
Minimum ..	..	..	..	3½	4½	7½	9	11	13	17	19
Mean ..	1–2	3	4	5	7	10	11	14	17	20	23
Maximum ..	..	..	..	8½	13	15	17	20	..	..	35

(*a*) *Rannes.*

This property, owned by Mr. J. L. Wilson and managed by Mr. C. McDouall, is 55 miles south-west of Rockhampton. On February 8, 1946, a dip was filled with 3,000 gallons of 1 per cent. Rucide (0·5 per cent. DDT), the water being softened with 1:1,000 Calgon. On February 8 and 9, 1,800 head of Hereford and Shorthorn cattle, comprising 400 grown bullocks and bulls, 500 breeders, and 900 mixed cattle 9 to 24 months old, were dipped, animals for subsequent examination being tagged at intervals throughout the dipping.

Tick infestation was light, and all stages were present at the time of dipping. Subsequent examinations showed that the kill was slow, reaching a maximum in 5–6 days, but was good, most animals being completely clean, and the remainder having very few survivors, the maximum being less than ten. The protective period for 45 animals checked ranged from 6 to 10½ days, and averaged 8 days. These cattle were dipped again by Mr. McDouall five weeks later, when carrying an extremely light tick infestation.

On February 23, 1946, the dip was stirred but not topped up, and 105 head were dipped. The initial infestation and results were similar to the above.

Between February 8 and May 3, approximately 5,000 head of cattle were dipped, and 4,000 gallons of 0·5 per cent. DDT suspension added in topping up, about 2,000 gallons of fluid remaining in the dip at that time. Ticks were very scarce throughout this period.

On May 5, as sufficiently infested stock were not available on Rannes, a neighbour, Mr. C. G. Guest, kindly allowed us to put 58 of his milkers and two bulls through the dip as a check. It had last been used on May 3, when it was topped up with 1,000 gallons DDT suspension, and 1,000 bullocks were dipped. Mr. Guest's cattle carried a light tick infestation, with all stages present. Subsequently, only six surviving ticks could be discovered on the 60 animals. The protective period before re-infestation with larvae was fifteen days.

To July 16, five months after the dip was charged, a total of 5,400 cattle had been dipped on Rannes, and 7,600 gallons of 1 per cent. Rucide had been added, including the original charging. Ticks were still extremely scarce, and no cattle had been dipped since May. On July 17, 70 bullocks belonging to Mr. Donovan, another neighbour, were put through the dip. The owner had had difficulty in controlling the ticks with arsenic, and Mr. McDouall stated that all stages were present at the time of dipping. They were examined on July 21 by Mr. Roulston, who reported that the cattle were clean and no surviving ticks could be discovered.

Recently, we have seen a mob of weaners, which were put through this dip on October 16. They showed numerous dead remains but no live ticks, indicating that the suspension was still active.

(*b*) *Toomba.*

Toomba is owned by Mr. E. E. D. White and managed by Mr. H. McKinnon; it is situated 70 miles north-west of Charters Towers in a well-watered basin. Ticks had been consistently heavy, and for the past four or five years increasing difficulty had been experienced in controlling them. Prior to the experiment, the station milkers had been dipped in arsenic weekly, but still carried heavy infestations.

On May 29, 1946, a dip was charged with 2,400 gallons of 1 per cent. Rucide; the water was soft, so no Calgon was added. On May 30, 176 heifers and 31 milkers and calves were dipped. The heifers had been dipped in arsenic three weeks previously, and carried a light-moderate infestation of all stages of ticks. The cows and calves had been dipped one week previously, and carried a heavy infestation of all stages; their hides were raw, thickened, and scabby.

Of twenty heifers kept back for close examination, nine showed surviving ticks seven days after dipping. These had been in the nymphal stage when dipped, and the maximum number found on a single beast was ten. Re-infesting larvae were first detected on the eighteenth day after dipping.

The cows showed a few surviving ticks on the head, and in one instance there was a line along the jaw, above which ticks were alive, while below it they were dead. These cows were very experienced in being dipped, and it was suggested that they managed to keep their heads more or less clear of the fluid. Apart from this, the kill on the cows and calves seemed to be complete. The protective period was twelve days.

From May 30 to September 14, 5,735 head were dipped, and 2,540 gallons of 1 per cent. Rucide added. Throughout this period ticks remained scarce. Cattle on the property were examined by Mr. Kerr on September 4–15, the results, with dipping information supplied by Mr. McKinnon, being set out in Table 2.

TABLE 2.—TOOMBA DIPPING RECORD.

Paddock.	Number.	Previous Dippings in DDT.	Last Dipping to Examination (Weeks).	Infestation.
Horse	25	May 30, July 17 ..	7	Very light
Long Pocket ..	186	Last dipping, Aug. 12	3½	Clean
Canal	796	Last dipping : most July 11–17, a few June 3	7–8 14	Very light, a few moderate
Oakey	147	May 31, July 11 ..	9	Very light
Lake	204	May 31, July 11 ..	9	Light, a few moderate
Nine Mile ..	105	July 3 only ..	10½	Moderate
Controls "Myola"	200	Dipped in arsenic, some three weeks, some six weeks previously		Light to heavy, majority moderate

On September 14 the dip was topped up with 560 gallons 0·5 per cent. DDT, and the 200 Myola bullocks, shown as controls in Table 2 and kindly made available by the owner, Mr. W. Jackson, were put through. It was only possible to examine them once after dipping, on the eighteenth day, when they were found to be clean, although they had been returned to Myola, where ticks had remained active during the period under review (June to September inclusive) and DDT had not been used.

(*c*) *Gracemere.*

Gracemere, owned by Archer Bros., is within a few miles of Rockhampton. A dip of 1,600 gallons capacity was filled on July 23, 1946. The available water was extremely hard (59 grains per gallon, recorded as $CaCO_3$), and the dip was charged with 168 lb. of Rucide and 40 lb. of Calgon. The suspension formed appeared to be of satisfactory fineness and stability.

On July 24, 182 head of mixed cattle, carrying a light to light-moderate infestation of ticks in all stages, were dipped. Kill was recorded as complete, except for an occasional engorged or semi-engorged nymph, and one or two adult ticks resulting from these nymphs were found on each of ten animals of 36 re-examined on the 22nd day. Re-infesting larvae were found on the 11th, 14th and 22nd days, but none beyond the medium-sized larval stage even at the last examination.

On July 24, two bullocks which had been used as controls for earlier spraying experiments and had not been dipped for several months were also dipped. They carried heavy infestations, and had a thick matted winter coat of hair carrying a lot of scurf and skin debris. The kill was incomplete, between 50 to 100 nymphs and adults surviving on each animal. One was re-dipped on July 29. On August 15, 22 days after the original dipping, the re-dipped animal was clean, and the other carried three adult ticks only.

Other cattle were dipped in the interim, and by September 5 the fluid in the dip was down to about 800 gallons. The suspension appeared normal, and was topped up with 450 gallons of water, 45 lb. Rucide, and 11½ lb. Calgon. One hundred and thirty-nine animals of the mob dipped six weeks previously were examined and dipped. They carried a light to moderate infestation of ticks in all stages. Six days after dipping 15 of the 21 kept for close examination were clean, seven showed one to four survivors, and one very large animal had a numbers of survivors on the shoulders. The protective period was not determined.

During this period, July to September, undipped controls had moderate to heavy infestations with all stages of ticks.

(*d*) *Innisfail.*

The dip used was at Goondi, within 5 miles of the town. It is owned by Mr. W. D. Davies, and the cattle dipped were his beef herd, and dairy cows belonging to Mr. A. Stoter. The dip was charged on August 4, 1946, with 1,860 gallons of 0·9 per cent. Rucide. The water was fairly soft, but 1:4,000 Calgon was added as a precaution.

On August 6, 156 head were dipped, comprising 26 dairy cows and two bulls, carrying a moderate infestation, and 128 heavily infested beef cattle of mixed ages and sexes; all stages of ticks were present.

Individual surviving ticks were found on about half the dairy cattle. The first re-infesting larvae were observed on the fifteenth day, and the first engorged adult resulting from re-infestation was found on the 35th day. On September 17, six weeks after dipping, they were considered by the owner and the Stock Inspector (Mr. J. Littleton) to be sufficiently infested to justify re-dipping. Owing to a misunderstanding, they were then sprayed with arsenic.

The beef cattle were in three mobs, one of which was available for regular examination. Practically all ticks were killed on this mob, only an occasional survivor being found at later examinations, while the protective period was estimated at fourteen days. When the cattle were put together for re-dipping on September 24, seven weeks after the first dipping, one mob (cows and calves in poor condition) was heavily infested, and the owner considered he should have dipped them a fortnight earlier; the second were lightly infested; and the third so lightly infested that dipping might with advantage have been postponed. All were re-dipped, with satisfactory control of ticks (Table 3) and a protective period of seven to nine days.

5. Discussion

These experiments were carried out over a wide range of country and tick populations from North to Central Queensland; and the Queensland Department of Agriculture and Stock has made observations with essentially similar results near Toogoolawah in South Queensland. Ticks on some of the properties were apparently "normal," but those on Toomba (and probably on Mr. Donovan's cattle) were "arsenic resistant."

Much remains to be done, particularly on the practical interval between dippings, the long-range effects of DDT on the populations of larval ticks in the pastures, and the balance between tick control and maintenance of immunity to piroplasmosis; but enough information has been obtained to give considerable hope for the future. The collective results of the experiments to date may therefore be reviewed briefly here as a starting point for future work.

(*a*) *Effect on the Cattle.*

The blandness of the DDT dipping in contrast to arsenic has been a striking feature to the owners of the cattle. Cattle rest and feed quietly after dipping, show no immediate irritation or later scalding, and a rapid improvement in the condition of their coats has been observed. It was also noted at Gracemere that they foraged more freely and widely after DDT dipping than after arsenic. No information is yet available about weights of beef cattle or butter-fat production of dairy cows.

(*b*) *The Kill of Ticks.*

As in the earlier spraying experiments, kill was slow, taking five to seven days to reach a maximum. Larvae and young nymphs disappeared within the first two days, and most adults by the fifth day. It is difficult to be sure whether the large adults were all killed, or whether some dropped off naturally. Engorged adults collected after spraying had usually failed to lay viable eggs, but a few kept at high humidity did (Horne, unpublished). The last to die were the engorging nymphs, and all the survivors subsequently found developing were in this stage when dipped.

It is difficult to estimate the percentage kill. However, no cattle were used for observation if their infestation was classified as less than "light" and unless all stages of the ticks could be readily found. Ticks are cryptic animals, except when approaching full growth, and surprisingly high populations are necessary even to qualify for the designation "light." Legg and Foran (1929) made a series of counts by stalling their animals and collected the adults as they matured. Their lowest count for an untreated control classed as "light" was 666, and the mean of ten "light" infestations was 3,489. We may safely conclude, therefore, that few if any animals in our series had less than 1,000 ticks on them prior to dipping.

One week after dipping in DDT, the animals in the groups kept for close examination fell into three classes: those on which kill was complete; those on which a very few (always less than ten, and usually only one or two) ticks survived and grew; and those on which

from about 20 to 100 ticks in various stages survived, and the kill was regarded as "incomplete." The distribution of these groups in these experiments is shown in Table 3.

TABLE 3.—THE KILL OF TICKS WITH DDT ONE WEEK AFTER DIPPING.

Experiment.	Original Infestation.	Number of Beasts Examined.	Tick Kill.		
			Complete.	Nearly Complete.	Incomplete.
Rannes 1 ..	Light	45	30	15	..
Rannes 2 ..	Light	30	27	3	..
Rannes 3 ..	? Light	6	6	..	..
Toomba 1 ..	Light-moderate to heavy	25	14	10	1
Toomba 2 ..	Moderate	20	20	..	..
Gracemere 1 ..	Light-moderate to heavy	36	24	10	2
Gracemere 2 ..	Light to moderate ..	21	10	10	1
Innisfail 1 ..	Heavy	23	13	10	..
Innisfail 2 ..	Moderate	12	9	3	..
Total ..	Light to heavy ..	218	153	61	4

The kill with 0·5 per cent. DDT was therefore complete on 70 per cent. of animals examined carefully, less than 100 but more than 99 per cent. on 28 per cent. of the animals, and more than 90 per cent. in the remaining 2 per cent. when allowance is made for the heavy infestations they carried.*

(*c*) *Protective Period.*

The most remarkable feature of DDT dipping is that, unlike arsenic, the residue kills all invading larval ticks for several days after dipping. Cattle were seached for live larvae very carefully, and the day on which they first appeared was recorded. They are extremely difficult to see, so the results were checked by later re-examination at times when the re-infesting ticks would have grown sufficiently to be found with reasonable certainty. The day of attachment was then calculated from Table 1. The results agreed satisfactorily with the earlier observations, so it may be taken that the protective periods recorded were reasonably accurate.

The mean protective periods recorded varied from eight and a half to more than eighteen days.†

* Two of the "failures" were suspected to be due to incomplete immersion. One of the four was re-dipped and cleansed of ticks five days after the first dipping, and the other three became practically clean as ticks dropped off during the period of protection from re-infestation.

† Mulhearn (Queensland Department of Agriculture and Stock), using sprayed cattle and a different method of observation, has had shorter complete protection times, but his results still indicate an enormous destruction of re-infesting larvae.

These results require qualification in two respects. In the first place, the season was bad in some areas, and natural re-infestation may have been retarded. This applied to the first observation at Toomba, where frosts inhibited attachment of larval ticks on controls for three days during the critical second week of observations, and it may have applied, too, to Rannes. It did not hold for Gracemere, where controls became re-infested normally, nor to Innisfail, where the tick population was high and active, nor probably to the second observation at Toomba. On the other hand, there is evidence that many re-attaching larvae die, and that those first seen do not necessarily survive. The effective protective period may therefore be longer than we have recorded.

(d) Interval Between Dippings.

With a protective period of ten days and a developmental period of 22 days, a dipping interval of about four weeks might be considered necessary. However, the rate of re-infestation has, except for one group of Mr. Davies' cattle, always been slower than might have been expected, and the interval to the second dipping has been more of the order of six to seven weeks. Even then, most of the cattle have been too lightly infested for us to attempt to record the kill of ticks.

There may be three reasons for this prolongation of the interval to the second dipping:—

(i) The dry (and, for part of the time, cold) season may have retarded re-infestation. This factor could have contributed to the result at Rannes, and doubtfully contributed at Gracemere and Toomba, but not at Innisfail.

(ii) The effective protective time, during which most of the ticks attaching died, may have been longer than the complete protective time recorded. There is some evidence from post-dipping counts to favour this, and it seems likely (and reasonable) that the period of complete protection is succeeded by one of partial protection during which the DDT is gradually disappearing from the beast.

(iii) While the cattle are still poisonous to ticks they act as poison baits, collecting the larval ticks from the pastures, and in this way they may produce a profound effect on the general tick population. We have as yet no accurate means to measure density of larval ticks on pastures, but we have a strong impression that the population is greatly reduced, and suspect that this may be the most important effect of all. The subsequent history of these cattle supports the suspicion.

The intervals between the second and subsequent dipping have generally been longer than those between the first and second. At Rannes we have never since the first dipping been able to find sufficient ticks to record kill, and have had to depend on the loan of neighbours' cattle to make observations; at the last inspection the Rannes cattle had not been dipped for three months. The position at Toomba is shown in Table 2, but the other experiments have not yet run sufficiently long to give information. Again, the dry season may have

played a part, though the presence of ticks on neighbouring properties makes it difficult to attribute the whole effect to season. In general, we are led to hope that, once control is well established (perhaps in bad areas by two dippings at fairly short intervals), the periods between dippings with DDT in seasons favourable to ticks may be two months or more.

(e) Stability of the DDT Suspension.

These dips have been used in accordance with normal practice; that is to say, they were charged, and then topped up from time to time with fluid to replace that removed by the dipped animals. This usually lay between ¾ and 1 gallon per head, and possibly some additional fluid was lost by leakage or evaporation. We do not yet know whether any significant changes of DDT content have occurred during the periods of usage, standing, and topping up with 1 per cent. Rucide. Judging by appearance, the suspension seems very gradually to settle out on standing, but to mix again readily (especially if there is a little silt in the bottom of the dip) when a few head are put through to stir it before dipping the main mob. On present indications, this would seem to be a sound precaution, even with freshly made suspensions.

Our longest experience so far has been for eight months at Rannes, at the end of which time the fluid appears to have been as active as it was at the beginning. At Innisfail, the fluid was active after six weeks' standing without topping up, but in all other observations fresh suspension was added before dipping, usually amounting to a fifth to one-third of the total volume of fluid. Thus, at the last detailed Rannes observations, the dip had not been used for three months, 500 gallons of fresh suspension were added to the 1,500 gallons of old suspension already present, and the cattle were then dipped.

So far as present experience goes, no term can be set to the duration of activity of this suspension.

(f) The Practicability of Dipping in DDT Suspensions.

DDT suspensions have certain advantages and disadvantages as dipping fluids. The advantages are:—

Efficiency in controlling ticks, whether arsenic-resistant or not.

Prolongation of interval between dippings, as compared with arsenic. (It has been estimated that dipping costs 2½d. per head for mustering and handling and ¼d. per head for wear and tear of yards, in addition to the costs of materials and labour to fill the dip.)

Not only control but probably extermination of buffalo fly on the property (Norris, 1947; Snowball, unpublished); probably also control of lice, and possibly of sandflies (Simuliidae and Ceratopogonidae) and bushflies (*Musca vetustissima*).

Absence of irritation or scalding, so that cattle will rest contentedly, or can be worked freely, immediately after dipping.

A probable, but as yet unassessed, improvement in condition and productivity resulting from a combination of these four effects.

The disadvantages are:—

It costs about 4½d. per head for materials to dip in Rucide as compared with ½d. per head for arsenic.

The suspension is more troublesome to prepare than an arsenic solution, and requires considerably more care and attention to detail.

The owner must weigh costs against benefits, and decide whether he is prepared to give the DDT suspension the intelligent handling it requires. In our present state of knowledge, we would unequivocally recommend the use of the suspension in areas where ticks are difficult to kill with arsenic, and buffalo flies are prevalent. In other areas, the balance is more delicate, and more experience is needed to decide whether the over-all benefits from DDT dipping outweigh the cheapness of arsenic dipping *plus* partial spraying with DDT (Norris, 1947) to control buffalo flies.

6. References

Legg, J., and Foran, J. L. (1929).—Some experiments on the treatment of tick-infested cattle with arsenical dipping fluids. *Proc. Roy. Soc. Qld.* 41: 83-120.

Norris, K. R. (1947).—The use of DDT for the control of the buffalo fly (*Siphona exigua* (de Meijere)). This *Journal*, p. 25.

Orr, L. W., and Mott, L. O. (1945).—The effects of DDT administered orally to cows, horses, and sheep. *J. Econ. Ent.* 38: 428-32.

Addendum (February, 1947)

Several developments have occurred since the above was written:—

(i) The long-range toxicity experiment mentioned on page 45 has now run for 51 weeks, without the cattle showing any detectable ill-effects.

(ii) In charging the dip, it is satisfactory to pour the drum of molten Rucide slowly directly into the vat, while the water is stirred vigorously with a paddle, thus saving the trouble of making a preliminary concentrate.

(iii) Analyses indicate that, after use, the DDT content of the dip often falls to 0·35 per cent. or less. In topping up, therefore, it is recommended that not more than 500 gallons of water be added for each 56 lb. drum of Rucide. If there is any doubt that the dip is killing ticks efficiently, samples taken *immediately* after stirring by about twenty head of cattle should be sent for analysis.

(iv) The dips mentioned in the paper have continued to give good control of ticks, while buffalo flies have remained difficult or impossible to find. Dips charged with 0·5 per cent. DDT have now been studied also at Ingham, Townsville, and Ayr, with essentially similar results to those recorded in the paper.

The Persistence of DDT on Cattle

*By R. H. Hackman, M.Sc.**

Summary.

Evidence is brought forward to show that the most important factor causing the removal of DDT from cattle sprayed with DDT preparations is licking, either by the animal concerned, or by another animal. Other factors have been investigated, viz. solar radiation and rain, growth and loss of hair, rubbing, production of skin secretions, absorption into the skin and hair and flaking of the epithelium, but these have been shown to play a minor role. It is concluded that the amount of DDT ingested by licking would not be sufficient to produce toxic symptoms.

I. Introduction

DDT† has been shown to be a very valuable insecticide for the control of the major cattle pests, viz. cattle tick, buffalo fly, horn fly, etc. in Australia, the U.S.A., and South Africa. The frequency of application of DDT preparations for the effective control of these pests depends upon the persistence of the DDT on the animals, and the longer the period of persistence, the lower is the cost of control.

Field tests have shown that deposits of DDT on living animal surfaces do not have the lasting effect expected from tests on household insects. On non-living surfaces, deposits have been reported to be effective over a period of twelve months or more, but under field conditions, deposits on living cattle surfaces remain effective only for from one to two weeks for preparations containing up to 2 per cent. DDT. Many factors, viz. production of skin secretions, growth and loss of hair, leaching action of rain, disturbances by body movement and wind, friction against external objects, and licking, which combine to keep the coat clean, may play a part in the removal of DDT. To these as possible causes for the removal of DDT must be added breakdown under solar radiation, absorption into the skin and hair, and removal by flaking of the epithelium.

Three methods are available for measuring persistence:

(*a*) chemical analysis of extracts from clipped hair;

(*b*) bioassay of clipped hair samples; and

(*c*) following the trend of the pest population in the field.

Chemical analyses are useful for the direct comparison of persistence on hair, though for accurate analyses, hair samples weighing several grams are necessary. When trends only are required, hair samples of about one gram suffice. For cattle tick and buffalo fly work there is no standard test insect for the bioassay of clipped hair, and random samples taken from field collected populations of larval ticks and buffalo flies have to be used. For a discussion of this method and method (*c*) see Norris (1947).

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† In this paper, by DDT is meant: 2:2-bis(p-chlorophenyl)-1:1:1-trichloroethane.

2. Solar Radiation and Rain

DDT shows absorption in the region 2200–2500A (ultraviolet) (with a maximum at 2360A in 95 per cent. ethanol) and also in the infra-red but none in the region 2900–7000A (sunlight) when dissolved in carbon tetrachloride. This and the fact that DDT is a comparatively stable molecule, being decomposed easily only by alkalis, suggest that DDT would be stable under atmospheric conditions. Reports on the stability of DDT to sunlight and/or ultraviolet light have been somewhat conflicting (Godkin and Swingle, 1945; Lindquist *et al.,* 1946) but when tested by biological methods it is generally agreed that the toxicity of DDT is reduced by exposure to these radiations. However, Lindquist *et al.* report only a small reduction in toxicity to houseflies and they adduce evidence that decomposition, when it occurs, is restricted to the surface. Chemical estimations generally do not show a rapid loss of DDT under such circumstances which would be in accord with surface decomposition. The following experiments support this conclusion. As residues from emulsions might conceivably catalyse the decomposition, films formed from both solutions and emulsions were used.

Preliminary work had shown that exposing DDT to bright sunlight or unfiltered ultraviolet light (Mercura Lamp 83, 240 volts, 80 watts) for periods of a few days did not cause any detectable decomposition. Therefore, it seemed more practical to use an instrument which would give an "intensified sunlight." A twin carbon arc Weatherometer was used which gave a radiation closely resembling sunlight, it being only very slightly richer in the ultraviolet. Thin films of DDT (150 gamma DDT per sq. cm. in glass petri dishes), prepared from an alcoholic solution of DDT and from an emulsion*, were exposed in the Weatherometer for 96 hours at 60°C., the humidity being relatively high as the base of the instrument consisted of a tank of water over which a steady upward flow of air was maintained. This period corresponds to an exposure for a period exceeding four months to the south-eastern Australian climate. Care was taken to see that all specimens received equal irradiation. The DDT was estimated by the dehydrochlorination method, after extraction with hot benzene, and only 56 per cent. of the pure DDT and 41 per cent. of the DDT prepared from the emulsion was recovered. Judging from the appearance of the films, it is possible that the high temperature caused loss of some DDT by evaporation. Despite the severe conditions of the experiment, this 50 per cent. loss of DDT, even had it occurred at ten times the rate, does not account for the recorded losses in the field. Moreover the films, after exposure, exhibited the normal toxicity of DDT to house flies. Fleck (1944) has shown that at 45°C. the rate of volatilization of DDT is very slow, and, under the experimental conditions, a 6·7 per cent. loss was recorded in 37 days.

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* Formula:

DDT	2·0 g.
Solvent naphtha (b.p. 90°–190°C.)	12·5 ml.
Wetsit	1·25 ml.
Water to	1 litre

Further evidence to support this and to show the effect of rain is given by Norris (1947) who exposed some cattle hides to the sun and rain, others to the sun but protected from the rain, and found that although the exposed hides had lost an appreciable part of their toxicity after three and a half months, they still killed buffalo flies. In two recent papers (Peairs, 1946; Matthysse, 1946) importance is attached to both rainfall and sunlight to account for the loss in toxicity of DDT on cattle.

3. Growth and Loss of Hair

Cattle are considered to have one coat of hair annually, but there is no special shedding period, shedding taking place slowly throughout the year (Duerden and Whitnall, 1930). Longer fibres are grown in the winter and shorter fibres in the summer so that the coat is longest at the end of winter. There is thus an apparent post-winter moult, especially in the colder climates. Excluding this period, it is inconceivable that the natural shedding of hair would materially affect the persistence of DDT over a period of less than a month or two.

4. Skin Secretions

The rate of secretion of sebaceous material is generally slow as is shown for Australian Illawarra Shorthorn cows at Canberra (Table 1). Selected areas on two beasts were washed with alcohol and then with warm soapy water, hair samples being taken immediately before washing, six hours after washing when the hair had dried and then at weekly intervals for a period of three weeks. Sebaceous secretions were considered to be that material extractable with petroleum ether (b.p.40°–70°C.). The figures show that 35 per cent. (mean result) of the secretion present on the hair at equilibrium had been replaced in 21 days. Provided the secretion does not move outward along the hair then this indicates a 35 per cent. increase in the amount of hair present. Available information (cf. Duerden and Whitnall, 1930) suggests that such a large rate of increase in the amount of hair present is highly improbable. From the figures given for one animal by Duerden and Whitnall it can be calculated that the maximum average increase in the amount of hair over a three week period is approximately 15 per cent. and this occurred during the period of

TABLE 1.

Period.	Mg. Secretion per g. Hair.		
	Animal 1.		Animal 2.
Before washing	39·3	37·9	47·0
6 hours after washing ..	3·7	0·0	4·6
7 days later	6·0	6·4	8·2
14 days later	12·2	10·8	10·1
21 days later	18·0	13·2	20·4

rapid winter growth. Therefore the sebum must move along the hair in the direction of the tip. The validity of taking the pre-washing result as an equilibrium figure is shown in Fig. 2, where the curve for Series 1 shows a more or less constant value over the last 24 days of the experiment, this value being approximately equal to that at the commencement of the experiment.

Even though the sebum moves outward along the hair and could consequently take the DDT with it, the results obtained from the following experiment clearly show that sebaceous secretions are not the most important factor in the loss of DDT.

5. Licking

Preliminary experiments had indicated that cattle do remove DDT from their hides by licking and it is significant that cattle, especially cows, are able to lick almost every part of the body save the head and neck. Moreover, cattle lick each other. At Yeerongpilly, Queensland, nine animals were sprayed as evenly as possible over an area of about two square feet on each side just behind the shoulder with an emulsion containing 2 per cent. DDT* using 500 ml. per beast. A mechanical atomizer was used, each area being sprayed to saturation. Before spraying three of the beasts the area to be sprayed was washed with alcohol and then with soap and water. These three and three more of the animals were prevented from licking themselves by fitting each beast with a piece of strong timber passing between the forelegs of the animal, the timber being kept in place by a headstall and surcingle (the latter being close to the forelegs). All animals were tethered in separate covered stalls during the entire experiment. The effects of direct sunlight were thereby eliminated. The tests were thus grouped in three series of three animals each:

1. Those in which no attempt was made to prevent the animals from licking the treated area.

2. Those in which precautions were taken to prevent the animals from licking the treated area.

3. Those in which precautions were taken to prevent the animals from licking the treated area which was washed before being sprayed.

An area of about one square foot was selected in the centre of each treated area and hair samples were taken from each side of each beast at the following intervals: before spraying, and 1, 3, 7, 15, and 31 days after spraying, and each hair sample was analysed for DDT and sebaceous secretion.

* Formula of emulsion concentrate:

DDT	12·8 per cent.
Benzene	15·8 per cent.
Dibutyl phthalate	18·7 per cent.
Wetsit	1·5 per cent.
Water	51·2 per cent.

For analysis the hair sample was extracted with petroleum ether (b.p. 40°–70°C.) which removed sebaceous secretions and DDT. The extract was filtered, evaporated to dryness, and the residue dried to constant weight at 100°C., it being established that this treatment did not bring about any decomposition of the DDT. The residue was dissolved in gracial acetic acid, filtered, and made up to an appropriate volume (50 ml. or 100 ml.). For the estimation of the DDT the colorimetric procedure of Chaikin (1946) based upon the intensity of colour produced when p–p′ DDT is heated in a mixture of glacial acetic acid and concentrated sulphuric acid was used, substituting a Lange photoelectric colorimeter with a suitable blue filter for the spectrophotometer.

The method was found to be reproducible, advantage being taken of the fact that the secretions were largely insoluble in cold glacial acetic acid. The error was estimated not to exceed 5 per cent. and the amount of sebaceous secretion was determined by difference. In all cases the clean hair was dried to constant weight and results expressed as mg. per g. clean dry hair. Expressing the results in this way enables the results from one hair sample to be compared with those from another since the results are then independent of the amount of moisture, dirt, sebum, DDT, etc. present in each hair sample.

The means and ranges of replicates for both DDT and secretion per g. hair are proportional, so by using logarithms the dispersion will be independent of the means. A statistical analysis was conducted using logarithms, and the antilogarithms or geometric means of the original values are presented in Tables 2 and 3, the logarithms being given in parenthesis.

TABLE 2.—TREATMENT MEANS, MG. DDT PER G. HAIR.

Days after Spraying.	Series 1.	Series 2.	Series 3.
1	13·7 (1·137)	24·1 (1·382)	7·9 (0·900)
3	3·9 (0·588)	19·6 (1·292)	6·7 (0·827)
7	..	12·7 (1·102)	5·0 (0·698)
15	..	5·6 (0·747)	6·2 (0·793)
31	..	6·3 (0·800)	9·2 (0·962)

Minimum difference for significance at 5 per cent. level for means of logarithms at the same date = 0·346.

Minimum difference for significance at 5 per cent. level for means between dates for the same treatment = 0·267.

TABLE 3.—TREATMENT MEANS, MG. SECRETION PER G. HAIR.

Days after Spraying.	Series 1.	Series 2.	Series 3.
0..	26·4 (1·422)	19·1 (1·282)	9·8 (0·992)
1..	74·5 (1·872)	93·8 (1·972)	31·1 (1·493)
3..	45·7 (1·660)	78·5 (1·895)	23·8 (1·377)
7..	20·7 (1·315)	62·8 (1·798)	16·1 (1·208)
15..	23·0 (1·362)	45·5 (1·658)	38·3 (1·583)
31..	19·6 (1·292)	28·8 (1·460)	77·3 (1·888)

Minimum difference for significance at 5 per cent. level for means at the same date = 0·302.

Minimum difference for significance at 5 per cent. level for means between dates for the same treatment = 0·221.

On any one occasion a sample was taken from each side of a beast, the location of these two samples being balanced relative to one another about the corresponding centres of the areas subjected to sampling, these areas being rectangular in shape and symmetrically placed relative to the spine. The same sampling sites were cut on all beasts on all treatments at the same date. This procedure may have led to a confounding of gradients on the sampled area with time of cutting so that in making comparisons between different times of cutting, this factor should be recognized.

In Fig. 1 are recorded the amounts of DDT on the three series of animals in mg. DDT per g. hair, and in Fig. 2 the amounts of sebaceous secretions in mg. secretions per g. hair. It is interesting to note that in Series 1 no DDT was detected after seven days. Earlier work using a variety of emulsions had given a value of 1 mg. DDT per g. hair or less after a period varying from seven to ten days. After spraying there was an immediate increase in the sebaceous secretions but the amount per g. hair had returned approximately to its pre-treatment value after one week. The immediate increase in sebaceous secretions after spraying is presumably due to a stimulation of production by the emulsion used because it is known (Regan and Freeborn, 1936; Freeborn *et al.*, 1934) that spraying cattle with petroleum oils or emulsions influences the physiological processes associated with the glands of the skin. The results given in Table 1 support this, for when cattle are not sprayed after washing no marked increase in secretions is recorded.

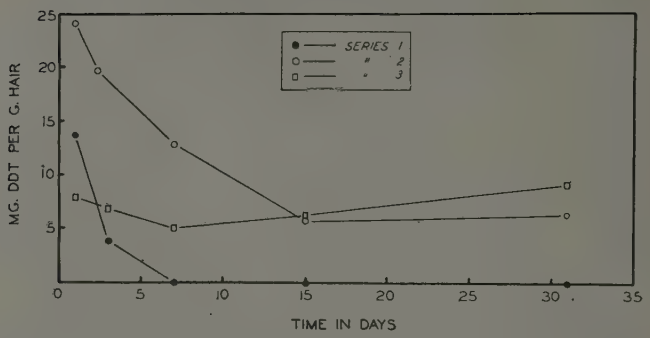

FIG. 1.—Amount of DDT on the hair of cattle in mg. per g. of hair.
Series 1: Cattle free to lick treated area.
Series 2: Cattle unable to lick treated area.
Series 3: Cattle unable to lick treated area which had been washed before spraying.

Comparing Series 1 and 2, the differences three days after spraying, and at all subsequent samplings, are highly significant, and must be regarded as real. In particular, Series 2 appears to stabilize at about 6 mg. per gram of hair while no DDT residue is observable in Series 1. The lower value for Series 1 at one day after spraying bears the same relative relation to Series 2 although the difference is not statistically significant.

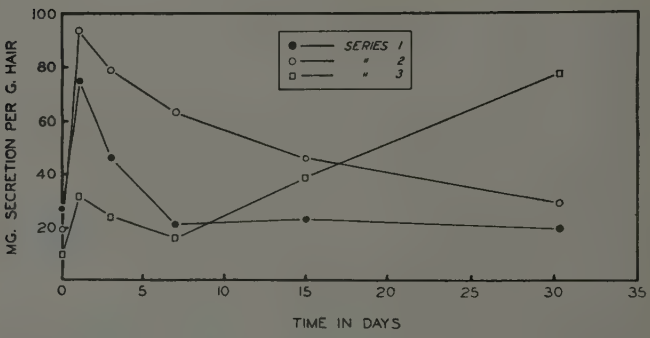

FIG. 2.—Amount of sebaceous secretions on the hair of cattle in mg. per g. hair.

As there was no difference in the treatment of the animals in Series 1 and 2 until after spraying, they all should have received a similar deposit of DDT at zero time. A reasonable extrapolation of the curves of both series (Fig. 1) is 30 mg. per gram of hair at zero time. Taking this value, the loss of DDT in Series 1 during the first day, is of the order of 50 per cent. Continuing at this rate the expected DDT residual after three days is about 4 mg., and after 7 days only 0·25 mg. per gram of hair. These calculated values are in accord with the actual values. This very rapid loss of DDT is not shown in either Series 2 or 3 and consequently licking, the only known variable, must be considered responsible. It was not possible to prevent the animals from rubbing which could have caused some loss but, as consideration of the results of Series 2 and 3 will show, this could not have been the major cause. Similarly the rapid loss of skin secretion produced immediately after spraying was due to licking. After seven days an equilibrium had been established and the animals were removing the secretion as rapidly as it was produced.

Series 2 consisted of animals which could not lick the treated area and there still remained on the animals 6·3 mg. DDT per g. hair at the end of the experimental period (31 days). The amount of DDT present dropped from a value of 24·1 mg. DDT per g. hair one day after spraying to an approximately constant and apparent equilibrium value after 15 days, the results not being significantly different from those for Series 3. Such a rapid initial fall can be accounted for only by rubbing, induced by irritation, removing flakes of the epithelium and skin secretions. A similar trend is shown for the skin secretions in Fig. 2. As in Series 1, spraying has induced a rapid initial increase in the amount of secretions on the hair which is followed by a rather rapid loss which is consistent with rubbing having removed the secretions. Even with this loss, the amount of secretions on the hair after 31 days was greater than that present before spraying.

Series 3 shows a somewhat clearer picture. The amount of DDT on the hair remained approximately constant throughout the entire experimental period, the observed variations not being significant. Washing removed the major part of the sebaceous secretions prior to spraying which left the hair considerably cleaner than that of the animals in Series 2. Consequently, less DDT, i.e. less emulsion, was retained by the hair of these animals than by the animals of Series 2. The amount retained, however, appears to be an equilibrium amount for the emulsion used since approximately the same amount was observed on the hair of animals of Series 2 after 15 days. As before, an increase in sebaceous secretions was recorded one day after spraying. Washing would remove much of the secretions from the skin and some of the secretions produced immediately after spraying would be used to replace this, thus giving a lower value after one day than that given by Series 1 or 2. There followed a slight decrease and then a continuous increase due, no doubt, to the accumulation of secretions, because the cattle were unable to remove them by licking. The reason for the decrease between one and seven days could be the same as that advanced in Series 2, viz. removal by rubbing which is in accordance with the slight decrease in the amount of DDT recorded after the first day. Even though irritation may lessen after one week

stimulation of production may still be present owing to the oil having come into contact more intimately with the skin. Consequently the amount of secretion present after 31 days (viz. 77·3 mg. per g. hair) may be abnormally high.

Since it is evident that cattle remove much of the DDT applied to their skin and hair by licking, the possibility of the DDT proving toxic to cattle becomes important. Of all domestic animals, cattle appear to be the most susceptible to DDT (Plummer, 1946; Orr and Mott, 1945). From the results of spray tests, it is unlikely that an animal weighing 500 kg. would retain on the hair and skin more than 50 g. DDT when sprayed (or dipped) over the entire body with an emulsion containing 2 per cent. DDT, i.e. 100 mg. per kg. of body weight. Assuming this to be removed uniformly over a period of seven days, there would be ingested daily approximately 14 mg. per kg. body weight, which from published data for the oral administration of DDT as a powder. would appear to be harmless. Added to this, cattle in warmer climates carry less hair than those in the colder climates and so would retain less DDT, and the tendency now is to use less concentrated LLT preparations. For the animals used in the experiments it is estimated that the amount of DDT retained after spraying, assuming the whole animal to have been sprayed, was about 50 mg. per kg. of body weight which, when removed in seven days by licking would correspond to the ingestion of 7 mg. DDT per kg. of body weight daily. No symptoms of DDT poisoning were observed. Plummer (1946) reports that cattle sprayed over the entire body with a preparation containing 5 per cent. DDT remained normal. Orr and Mott (1945) have shown that the daily oral administration of 100 to 200 mg. DDT per kg. of body weight as a dry powder to cattle for a period of three weeks is not acutely toxic and that most of the material is eliminated from the body, although small quantities may be taken up by the blood stream. Telford and Guthrie (1946) secured no definite evidence to indicate that any harmful effects resulted from spraying a Holstein cow with a preparation containing 10 per cent. DDT.

Stimulation of secretion production would, no doubt, increase the amount of licking which would remove the DDT more rapidly. Moreover, it seems reasonable to assume that the old secretion carrying the DDT, either in solution or suspension, is pushed towards the end of the hair by new secretion and since the old secretion is removed first, the DDT is lost. If this stimulation of secretion production could be prevented then the period of persistence may well be increased. This may be possible if an aqueous instead of an oil carrier is used for the DDT, e.g. a water suspension. The advisability of adding to a DDT emulsion a substance to make it so unpalatable to the cattle that they would refrain from licking is doubtful because the cessation of licking may be injurious to their health.

6. Absorption into the Hair

Absorption into the hair has been advanced as a factor to account for the loss in toxicity of DDT on cattle. Chemical analyses depend on extraction of the hair samples with a solvent to remove the DDT; such treatment must recover any DDT actually present inside the

hair. The DDT analyses, obtained in the previous experiment, eliminate absorption into the hair as a factor of any importance contributing to the loss in toxicity of the DDT. No sorption of DDT, by cattle hair, from DDT solutions (alcohol and toluene) could be detected. Cattle hair removed, by sorption, small amounts of DDT from emulsions containing 2 per cent. DDT (3 mg. per g. hair; about 3 g. per beast). Little is known about absorption into the skin, but the work described above shows that such a process, if it does occur, cannot be of importance in removing DDT from the hair (cf. Series 2 and 3).

7. Conclusion

From the foregoing work, it is concluded that in the field the major cause of the removal of DDT from the hair of cattle sprayed with DDT preparations is licking, eitner by the animal concerned, or by another animal. All the other factors discussed play a very minor role and of these factors the effects of rubbing, solar radiation, and the leaching action of rain would appear to be the most important. In earlier work it soon became evident that the composition of the emulsion had little effect on the period of persistence and that increasing the DDT concentration from 1 to 2 per cent. produced but a very small increase in the persistence period. These observations are readily explained when it is realized that it is the animals themselves which remove the DDT. These results also suggest that adequate control of ticks and flies as distinct from eradication, would be obtained by preparations containing less than 1 per cent. DDT.

8. Acknowledgments

The author's thanks are due to members of the Division of Economic Entomology for advice, to the Cattle Tick Section for making the animals available in Queensland and for assistance in handling the animals, to Mr. G. A. McIntyre, who was responsible for the sampling pattern and for the statistical analysis of the results, and to the Superintendent, Munitions Supply Laboratories, Melbourne, for the use of the weatherometer.

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The Etiology of Take-all Disease of Wheat

3. Factors Concerned with the Development of Take-all Symptoms in Wheat

*By N. H. White, D.Sc.**

Summary.

1. In a glasshouse experiment using soil from take-all and "healthy" areas, take-all symptoms developed in wheat when the soil was not steam-sterilized and when steam-sterilized but inoculated with *O. graminis*.

2. There was no difference in the amount of take-all when the wheat was grown in soils taken from these two field localities. It was suggested that soil differences, if they existed, did not influence the pathogenicity of *O. graminis* on wheat.

3. In wheat grown in steam-sterilized soil from either of these two localities no take-all symptoms occurred.

4. In steam-sterilized soil inoculated with *O. graminis* and a dry top soil maintained throughout the growing period, take-all symptoms developed in all plants.

5. In this experiment whiteheads were developed by all plants producing ears.

6. Examination of white-eared and normal-eared plants taken from the field during three seasons revealed that there was significant proportionality between the functioning roots and the load of the shoot system.

7. The relationship of the functioning roots to the shoot load was discussed with reference to the development of the whitehead condition and the collapse of the plant.

In the second part of this series of studies it was shown that *Ophiobolus graminis* appeared to be the primary invading organism of the roots and crowns in take-all affected wheat in the field. Also that the distinction between the condition of the roots and crowns of white-eared and normal-eared plants in the field appeared to be one of degree only. There remained the need to establish the pathogenicity of *O. graminis* on wheat grown in soil from the field under observation, and to account for the conditions which determined whether a plant became a white-eared or normal-eared plant, once affected with *O. graminis*.

1. The Pathogenicity of *O. graminis* on Wheat in Sterilized and Unsterilized Soil from Take-all and Healthy Areas of the Same Field

Isolates of *O. graminis* obtained from affected plants in the field reported in the first part of this series, were submitted to the usual seedling pathogenicity test in pots under glasshouse conditions. The isolates showed variability in pathogenicity ranging from mildly to severely pathogenic. A moderately pathogenic strain was used in the following investigations.

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In the first part of these studies it was stated that the location of a take-all patch may be due to soil differences or to the concentration of *O. graminis* inoculum in localized areas. Therefore for the testing of the pathogenicity of *O. graminis* on wheat, soil from the site of take-all patches and healthy areas was used in order to determine whether the location of the soil affected the severity of the symptoms when the same isolate of the fungus was used.

The pathogenicity test was carried out under glasshouse conditions so that some degree of control of environment might be obtained, and was conducted in the 1940 season.

Soil taken from the top six inches was collected from some of the areas known to be badly affected with take-all in the 1939 season, and a similar lot of soil was collected from adjacent areas that produced healthy plants. The soil from these two areas was air-dried, and sieved through half-inch mesh wire-netting to remove stones. No attempt was made to exclude diseased plant material.

To each of 80 Wisconsin temperature tank cans eight kilograms of soil were added, 40 cans contained soil from take-all areas and 40 cans from healthy areas. Twenty of these cans containing soil from each of the areas were steam-heated for six hours. Paper was tied over the tops of these and they were allowed to stand for three weeks before commencing the experiment. There were in all, four lots of soil each contained in twenty cans. They were take-all area soil steam-heated, take-all area soil unsterilized, healthy area soil steam-heated, and healthy area soil unsterilized. The soil in ten cans of each of these four lots of soil was inoculated at seeding with straw inoculum of a moderately pathogenic strain of *O. graminis.*

Before seeding with wheat, the soil in the cans was moistened to about field capacity. Inoculum was so placed that it was 2 inches below the surface, and surface-sterilized " Bencubbin " wheat seed was placed half an inch above the inoculum. Eight seeds were sown in each can and the cans were randomized. Water was not added until the seedlings emerged and from then on the soil was kept moist by adding water to the top of the soil as required. However, no attempt was made to control the soil moisture at a definite level, but every precaution was taken to avoid creating conditions of drought or waterlogging.

Four weeks from the commencement of the experiment the number of plants in each can was reduced to four. At heading-out stage, two cans were removed from each of the four treatments containing soil from take-all areas, and one can was removed from each of the four treatments containing soil from healthy areas. The plants in these cans were dug up and the roots examined for lesions. Many of the lesioned roots were plated to ascertain their microfloral content.

Plants in unsterilized soil (whether inoculated or not) and steam-sterilized inoculated soil had lesions on about 75 per cent. of their crown roots, and the seminal root system on nearly all these had completely rotted away. No lesioned roots were found on the plants from the steam-sterilized uninoculated soil. Plating of the lesioned roots from each treatment gave the usual types of fungi found at heading-out in lesioned wheat roots, including species of *Fusarium,*

Penicillium sp., *Helminthosporium sativum,* and *Curvularia* sp., reported in Part 2. However, *O. graminis* was obtained in about 20 per cent. of the roots plated.

Results.

In each of the treatments data were obtained on (i) the percentage of seedling blight, (ii) the amount of tillering at jointing, (iii) the number of tillers producing ears, (iv) the yield of grain, and (v) the percentage of take-all in the mature plants. A summary of these data are given in Table 1. As a result of analysis of the data from all the treatments, there was no significant difference between soil types, i.e. take-all area soil, as against healthy area soil, whether inoculated or not. For all measures of pathogenicity the difference between inoculated and uninoculated sterilized soil was highly significant. For unsterilized soil there were significant differences between the uninoculated and inoculated series only in the percentage of plants with seedling blight and the number of tillers per plant.

Take-all symptoms as manifested at maturity varied from plants that died prematurely at heading-out either before or after the ears had emerged (white ears), to plants that were hard to distinguish from the normal ripe plants but yielded very shrivelled grain. To a large extent this obtains under natural field conditions, but owing to the artificial conditions of the greenhouse the distinction between a mature ripened plant and a prematurely ripened plant was even less apparent; this was due largely to the fact that diseased plants did not show the stunted growth as seen in the field, and ripening was more gradual in the greenhouse. Upon harvesting the criterion of a take-all plant was one that produced an average grain weight of less than 0·053 g. per grain. This standard was based on the weight per grain of known take-all plants collected in the field.

The data revealed that take-all occurred in all treatments except in the sterilized uninoculated soils from both take-all and healthy areas.

Steam-heating of the soil apparently had a twofold effect.

(i) The pathogen already in the soil was killed, as evidenced by the absence of symptoms of disease and root lesions on plants grown in sterilized soil in contrast to the symptoms and root lesions on plants grown in sterilized inoculated soil.

(ii) Increased vigour of the wheat plants, manifested in density and greenness of foliage, early maturity, height of the plants, number of tillers attaining maturity, and total yield of the plants seen in Fig. 1. This phenomenon resulting from steam-heating of soils of different types was noted before by the writer and there are frequent references to it in the literature. Johnson (1919) has summarized the theories explaining this, and the results of his investigations suggest that the beneficial action of heating soils is due largely to the liberation of ammonia.

Potter and Snyder (1918) found that heating the soil " caused an increase in soluble non-protein nitrogen." Piper (1942), however, found that the availability of copper was significantly increased by partial heat-sterilization of copper-deficient soil, and suggested that the increased availability of copper was either a direct result of heat,

or by the elimination of competition from some soil microflora and fauna. Millikan (1941) claims that the beneficial effect of steam-sterilization of Wimmera soils is due to the removal of soil inhabiting organisms that compete with the plant for soil nutrients and states that " formalin-sterilization induced a similar or better improvement of growth to steam-sterilization." In the writer's experiment, the occurrence of seedling blight and the white-head condition in plants grown in the steam-sterilized soil inoculated with *O. graminis* suggests that this fungus is able to attack the roots of the wheat plant in spite of the enhanced nutritional benefits to the plant through steam-sterilization of the soil.

FIG. 1.—The effect of steam-sterilizing soil on the growth of wheat. From left to right: Steam-sterilized soil from take-all area, steam-sterilized soil from healthy area, unsterilized soil from take-all area, unsterilized soil from healthy area.

In soil inoculated with *O. graminis,* seedling blight symptoms became apparent three weeks after seeding. Seedlings with disease symptoms removed at this time had lesions on their seminal roots and showed a marked tendency for early development of crown roots when compared with healthy seedlings. Seedling blight was followed by a retardation of growth and lateness of maturity, and a reduction in the amount of tillering, and sometimes culminated in the development of white-heads.

Take-all occurred in both inoculated and uninoculated unsterilized soil, but a greater number of tillers failed to mature in the uninoculated soil. This is seen in Table 1, when the mean number of tillers per plant at jointing is compared with the mean number of ears per plant. The significant points of difference in these two treatments are to be found in the amount of seedling blight, of tillering, and incidence of take-all.

TABLE 1.—SUMMARY OF DATA ON THE PATHOGENICITY OF *O. graminis* ON WHEAT IN STERILIZED AND UNSTERILIZED SOIL FROM TAKE-ALL AND HEALTHY AREAS.

	Soil from Take-all Areas.				Soil from Healthy Areas.			
	Sterilized.		Unsterilized.		Sterilized.		Unsterilized.	
	Control.	Inoculated.	Control.	Inoculated.	Control.	Inoculated.	Control.	Inoculated.
Mean number tillers per plant	5·5	3·5	4·9	3·0	5·2	3·1	4·3	3·3
Mean number of ears per plant	5·1	2·8	2·8	2·3	5·0	2·8	2·4	2·4
Yield per plant in grams ..	5·14	3·16	3·21	3·40	5·83	3·53	2·77	3·43
Percentage of plants showing seedling blight.. ..	0	52	0	25	0	55	0	70
Percentage of take-all plants	0	63	50	47	0	63	56	44

The complete absence of take-all in the uninoculated steam-sterilized soil, and the lack of lesions on the roots of these plants, compared with abundance of take-all together with the high incidence of root lesioning on plants grown in steam-sterilized soil inoculated with *O. graminis,* confirms the primary causal relation of this fungus to the disease, suggested in Part 2 of these studies.

Although take-all occurred in both inoculated and uninoculated unsterilized soil and in inoculated sterilized soil the number of take-all plants in each can containing four plants varied. On removing the soil from the cans at the completion of the experiment the relatively dry condition of the upper portion of the soil was noted in cans with a higher incidence of take-all as compared with the soil in cans with low number of take-all affected plants.

2. The Effect of Dry Top Soil on the Development of Take-all Symptoms

Field observations indicated that a relatively dry top soil was an important contributing factor in the development of take-all symptoms in the wheat plants when the seminal root system had been destroyed by parasitic organisms. The greater frequency of the white-head condition in cans with a relatively dry top soil compared with those containing moist top soil confirms field observations on comparable soil conditions. An experiment was therefore undertaken in 1941 to determine the effect of a dry top soil on the development of take-all symptoms. Soil collected from the top 6 inches of a fallow area in the naturally take-all affected field was air-dried, sieved, and steam-heated for six hours and allowed to stand several weeks before the experiment was commenced. The soil was found to have a field capacity of 18 per cent., and a permanent wilting coefficient of 6·8 per cent. of the dry weight.

Eight kg. of the air-dried steam-sterilized soil were weighed in each of 40 Wisconsin temperature tank cans. The soil in twenty cans was brought to field capacity by adding the requisite amount of water, and the soil in the remaining twenty cans was brought to 65 per cent. of the field capacity by thoroughly mixing in the necessary amount of water. Two L-shaped glass irrigators, 1 cm. in diameter, were so placed in the soil in each can, that the outlet of one of them was one-third and the outlet of the other two-thirds of the distance from the bottom of the soil to the top of the soil. Straw inoculum of a six-weeks-old culture of *O. graminis* was placed in ten cans of each of the dry and moist series, at a depth of 2 inches below the surface. Three surface-sterilized and germinated (two days) wheat seeds were placed in each can at a depth of 1½ in. (The seed used in this experiment was from a single plant and the progeny of three generations of selfed "Bencubbin" wheat.) The water lost from the soil in each of the cans was replaced by adding enough water through irrigators to bring the cans back to their original weight. During the first two months of the experiment this was done only once a week, but after that and until the plants were ripening, every three days. Although there were fluctuations in moisture content of the soil below the two initial standards, one series was maintained in a wet condition throughout, while the other series was kept in a moist condition only in the lower part of the soil, the top 1½ inch gradually drying out simulating the condition frequently observed in the field.

Results.

By inspection, differences between each of the treatments were quite obvious long before the plants reached maturity, as shown in Fig. 2.

By the time the experiment was completed, differences appeared even greater, as shown in Fig. 3. Quantitative data when analysed proved that these differences were significant. A summary of the data is given in Table 2.

It will be seen that take-all disease occurred in soils wet throughout and in soils partially wet, when inoculated with *O. graminis*; but all plants in the series with a dry top soil were diseased plants, whereas only 54 per cent. of the plants in the series with wet soil throughout

showed symptoms of disease in the shoots. Furthermore, in the dry top soil series the symptoms were indistinguishable from those found in the field, which vary from plants killed in the seedling, jointing, and in-the-boot stages as well as at anthesis when the white-head condition is observed. All these stages, together with the stunting effect, were obtained in the dry top soil series as is illustrated in Fig. 3. On the other hand, symptoms shown by plants in the inoculated wet-soil series were atypical, and the plants gave the usual delayed maturity following seedling blight, seen in Fig. 2.

FIG. 2.—The effect of growing wheat in steam-sterilized soil with a dry and wet top soil. From left to right: Dry top soil control, wet top soil control, dry top soil inoculated, wet top soil inoculated. (Each treatment in two rows.)

The inoculated treatments in both the soil moisture series are significantly different from the controls in all the data shown in Table 2. This conforms with previous observations and the result obtained in the previous experiment. The introduction of *O. graminis* into the soil seriously affects the growth of wheat plants as well as causing the development of take-all symptoms.

The difference between the control series in the dry top soil as compared with the control series in the wet top soil is seen most conspicuously in the height and number of tillers as well as in yield and number of crown roots per plant (see Figs. 2 and 3). The significantly smaller growth of the plants in the dry soil series is explained by the findings of Briggs and Shantz (1913), Shantz (1927), Veihmeyer (1927), and Martin (1940). They have shown that it is impossible to maintain a mass of soil at a uniform moisture content below field capacity, and that the addition of less water than required to bring the soil to field capacity would result in some of the soil

TABLE 2.—SUMMARY OF DATA ON EFFECT OF DRY TOP SOIL ON THE INCIDENCE OF TAKE-ALL, AND GROWTH OF WHEAT IN SOIL FROM A TAKE-ALL AFFECTED FIELD.

Initial Moisture Condition of Soil.	Treatment.	Percentage of Take-all.	Mean Number of Tillers per Plant.	Mean Height per Plant.	Weight of Grain per Plant.	*Grain Rating per Plant.	Mean Number of Crown Roots per Plant.	Mean Number of Non-lesioned Crown Roots per Plant.
				cm.	g.			
Field capacity	Control ..	0	7·9	99·6	9·8	9·8	60·3	60·3
	Inoculated ..	54	3·9	74·3	4·1	7·1	27·9	6·5
Field capacity, 65 per cent.	Control ..	0	5·7	86·1	6·5	9·6	46·4	46·4
	Inoculated ..	100	2·8	40·3	4·3	4·3	37·0	11·1
Control compared with inoculated	Mean difference	..	3·5 xxx	35·5 xxx	4·0 xxx	4·0 xxx	20·9 xx	44·5 xxx
Field capacity compared with 65 per cent. field capacity	Mean difference	..	1·6 x	23·7 xxx	1·5	1·5 x	2·4	4·6

Level of significance.—xxx $P < 0{\cdot}001$; xx $P < 0{\cdot}01$; x $P < 0{\cdot}05$.

* Grain rating refers to fourteen grades of grain size ranging from 0·000 to 0·070 per grain, with a uniform interval of 0·005 g. per grade. Ratings of 0·7 are equivalent to the rating of take-all plants in the field.

remaining unchanged so that plants growing in soil with an initial moisture content below field capacity would be forced to grow in a smaller volume of soil. Therefore in the series commenced at 65 per cent. field capacity the plants were forced to grow in a smaller volume of soil than those growing in the soil with an initial soil moisture at field capacity. In the dry top soil series then, the lower 65 per cent. of the soil was brought to field capacity at each weighing and it was this amount of soil that the roots had to draw on for plant nutrients. Plants in the inoculated soil commenced at 65 per cent. of field capacity simulated the field appearance when dry conditions prevail at any stage during their development if their roots were partly destroyed by the fungus. Under these circumstances when the top soil dried out, the new crown roots developing in this zone were unable to obtain sufficient moisture to maintain the minimal water requirement of the plants. On the other hand, in the soil brought back to field capacity at each weighing the top soil was always moist and new crown roots, whose development is always stimulated by root destruction, were able to replace the destroyed roots and maintain the water supply to the plants. However, the limiting effect on growth of the plants through root destruction by *O. graminis* is readily seen in the inoculated wet top soil series when compared with the controls (see Fig. 2).

3. The Relation of the Root to the Shoot System in White-eared and Normal-eared Plants

In an attempt to account for the conditions which determine whether a plant becomes a white-eared or normal-eared plant, the relative amount of shoot tissue to the number of surviving roots in both kinds of plants was critically examined during three seasons.

FIG. 3.—The effect of growing wheat with a dry and a wet top soil as seen when the plants are ripe. From left to right as in Fig. 2. It will be noted that the plants in the dry top soil inoculated can are typical take-all affected plants.

Method.

Samples of white-eared and normal-eared plants were collected in each of the three seasons 1940, 1941, and 1942 on plots sown continuously to wheat, and in 1942 on a plot sown to wheat for the second time after one year's fallow and a plot sown to lucerne in the previous year.

The samples were collected each year at the critical period, that is between anthesis and ripening, when it was easy to distinguish the white-eared plants from the intermediate slate-green plants; which later produced pinched grain, and the normal green-eared plants bearing plump grain. Only plants with fully emerged ears were collected, so that a very large proportion of white-eared plants which had one or more ears in the boot at the collapse stage were passed over. This procedure tended to restrict the white-eared samples to plants which collapsed latest in the season and which therefore should have been least affected of white-head samples by root destruction after collapse. The fact that plants in the selected white-eared sample were clearly distinguished from less and more severely affected plants probably left less room for variability than with normal plants which may range from just better than the intermediate slate-green to complete freedom from fungal attack. The plants were collected on an ear class basis and in order to secure a sufficient number in each ear class up to four ears, a rough tally was kept of the number collected in each class, and the white-eared plants were chosen so as to keep the numbers roughly equal. Whenever a white-eared plant was pulled, the near neighbourhood was searched for one or two normal plants of the same ear class. This was usually achieved within 2 feet of the white-eared plant.* In 1942 the procedure had to be reversed where, on finding a normal-eared plant, the neighbourhood was searched for a matching white-eared plant. In all instances the selection of the plant was determined solely by the shoot condition. In each plot all samples were drawn from an area not exceeding 200 feet by 50 feet.

Most of the plants collected had earless tillers 6 to 9 inches high which were dead before the ripening stage. The undeveloped tillers apparently are of some importance, however, because the number of crown roots for plants in an ear class increased in proportion to the number of partially developed tillers. Therefore in tabulating the data it was necessary to prepare two-way tables so that each plant could be classified according to the number of eared tillers and partially developed tillers.

The plants were examined in detail, and data on the following were obtained in 1940 and 1941: (i) Number of eared tillers; (ii) number of partially developed tillers; (iii) length of each eared tiller (length of last internode in 1941); (iv) total number of spikelets per ear; (v) total number of crown roots and number of crown roots with

* When examining the plants in the laboratory many plants with high tiller number proved to be two or more inter-locked plants so that the numbers finally recorded were greatest for one-eared plants.

lesions;* (vi) total number of seminal roots and number of seminal roots with lesions; (vii) condition of sub-crown internode (lesions or no lesions). In 1942 the length of the eared tillers and the total number of spikelets per ear were omitted.

Results.

Because it would be impracticable to present the two-way tables for the three seasons for each particular and since the mean number of undeveloped tillers (1 to 1·5 per plant) is about the same for both white-eared and normal-eared plants of the same ear class, only the averages of all plants of the same ear class are presented. These are given in Table 3 which shows the mean values for each ear class for normal and white-eared plants in 1940, 1941, and 1942.

The results for the first two seasons differ markedly from the 1942 season in the data on the number of surviving crown and seminal roots and in the percentage of sub-crown internodes and first internodes with lesions. These differences appear to be related to the much higher rainfall of this last season (see Table 4), when 2,148 points fell between May and November inclusive in contrast to 626 and 899 points for 1940 and 1941 respectively. The data convey the general impression that with increasing moisture in the spring there is a decline in the number of surviving roots required to carry the white-head plants up to the point of collapse at the standard condition of fully emerged ears.

In 1940 the difference in the numbers of surviving crown roots for white-eared and normal-eared plants was small, so that for this season the number of surviving seminal roots must have been all-important. At the writer's suggestion root amputation experiments were carried out during this season in this field by Ludbrook (1942). It was found that severing the sub-crown internodes affected the plants more severely at all stages of growth investigated than did amputation of the crown roots, and thus provided supporting evidence of the importance of the seminal root system during this season (see Table 3). In 1941 the difference in surviving crown roots of white-eared and normal-eared plants was greater. This suggests that the crown root system was more effective in maintaining the plant in the later stages of growth than in 1940, and this again appears to be related to the spring rainfall which was slightly better in the 1941 season (see Table 4). In both seasons the number of surviving crown roots of white-eared plants increased with the number of ears produced by the plant, while the mean number of surviving seminal roots was about constant.

In 1942 practically all the crown and seminal roots of the white-eared plants had lesions. The moist conditions of the soil probably meant that only a few functioning roots were necessary to sustain the plant to the point of collapse and plants with more functioning roots would come into the intermediate class. The contrast between the number of functioning roots in this and previous seasons may have been exaggerated by much rotting of roots in the moist soil subsequent to collapse but prior to examination.

* The criterion adopted for designating a root with lesions was: A root showing marked dark brown to black discolouration of tissue completely encircling the root for a variable distance and which in breaking revealed a blackened or discoloured stele usually rendered brittle through necrosis.

TABLE 3 (PART I.).

Ear Class.		Number of Plants.			Total Crown Roots.			Lesioned Crown Roots.			Surviving Crown Roots.		
		1940.	1941.	1942.	1940.	1941.	1942.	1940.	1941.	1942.	1940.	1941.	1942.
1	Normal ..	65	53	34	15·8	16·7	13·2	1·7	5·3	8·0	14·1	11·4	5·2
	White ..	40	73	78	11·9	13·5	11·7	7·6	8·6	9·9	4·3	4·9	1·8
2	Normal ..	55	42	26	20·1	26·0	20·0	3·3	7·4	1·5	16·8	18·6	18·5
	White ..	36	56	27	27·0	23·8	22·1	12·0	12·7	20·2	15·0	11·1	1·9
3	Normal ..	57	33	27	31·8	35·4	30·1	4·0	8·6	3·8	27·8	26·8	26·3
	White ..	30	42	30	26·1	32·1	23·2	14·1	19·3	20·1	22·0	12·8	3·1
4	Normal ..	12	18	27	38·7	42·3	39·2	4·0	10·4	7·0	34·7	31·9	31·9
	White ..	10	14	25	43·2	45·3	37·5	14·1	23·1	37·0	29·1	22·2	·5

TABLE 3 (PART II.).

Ear Class.		Surviving Seminal Roots.			Percentage Sub-crown Internodes without Lesions.			Percentage First Internodes without Lesions.		
		1940.	1941.	1942.	1940.	1941.	1942.	1940.	1941.	1942.
1	Normal ..	3·0	3·0	1·1	91	66	9	97	98	71
	White	·5	·7	·1	25	18	5	80	67	22
2	Normal ..	3·5	3·3	4·5	87	64	77	98	100	84
	White	·5	·6	·1	28	27	0	69	84	15
3	Normal ..	3·9	4·5	3·4	82	82	67	93	91	88
	White	·7	·9	·2	40	29	3	93	31	20
4	Normal ..	4·4	3·7	3·2	100	78	48	100	89	66
	White	·6	·7	·0	20	14	0	50	43	0

It would be appropriate at this point to note the trends apparent within the ear classes in the 1940, 1941 data (shown in Table 3). (*a*) White-eared plants—the total number of crown roots increased at the rate of 3·3 per undeveloped tiller but there was only a slight increase in non-lesioned crown roots per plant. There was no corresponding tendency for surviving seminal roots per plant to increase or decrease. There was no apparent trend in the percentage of plants with sub-crown lesions. (*b*) Normal-eared plants—the total number of crown roots increased at the rate of 3·5 per undeveloped tiller, there being no tendency for the number of roots with lesions to increase or decrease. For other data the trends were similar to those for the white-eared plants. In 1942 the tendencies in the crown and seminal roots were the same as for the previous seasons except that there was no evidence of any trend in the very small numbers of surviving crown roots.

TABLE 4.—RAINFALL IN POINTS AT CANBERRA DURING 1940, 1941, AND 1942, WITH STAGE CROP DEVELOPMENT.

Month.	1940.	1941.	1942.	Stage of Crop.
January	185	674	22	Stubble
February	10	257	131	
March	6	148	151	
April	696	54	7	Sown
May	115	186	638	Seedling
June	52	114	338	Seedling
July	29	48	194	Early jointing
August	91	105	229	Jointing
September	244	262	244	Late tillering
October	25	124	174	In boot
November	70	90	431	Anthesis and dough
December	177	96	112	Ripe (harvested)

It was hoped that it would be possible to show that if a seminal root was rated as effective as k crown roots, the value of k to depend on the season, then the total effective root system of white-eared plants would be proportional to the number of ears. Values of 12 and 2 for k best satisfy the data for 1940 and 1941 respectively. This approach is of interest but cannot be regarded as entirely satisfactory owing to its sensitivity to small systematic errors in assessment of root lesions.

From these data it would seem that the seasons in 1940 and to a less extent in 1941 were conducive to the development of the so-called "dry weather take-all" (Russell, 1934) and data for these seasons

provided evidence of a relationship of the shoot system to an effective absorbing root system in white-eared plants. In 1942 a relation of this sort was not apparent but it may have existed at the initial development of white ears. Subsequent rotting of the few roots per ear functioning at collapse would destroy the evidence of proportionality.

4. Discussion

The pathogenicity of *Ophiobolus graminis* in relation to take-all disease has been established by many investigators and is reviewed by Garrett (1942). Past workers have used the effect of infection on seedling plants and on yield as criteria for the pathogenicity of *O. graminis* on wheat. This has proved useful in assessing the capacity of the fungus to attack root tissue, but does not show the relation of the fungus to the final stage of take-all disease manifested as white-eared plants known as "whiteheads," and this is the dominant field symptom. The experimental development of the whitehead condition is claimed by a few workers only (Geach, 1932; Garrett, 1941; White, 1942; and Angell, 1943). However, the experience of all was that only some of the plants became typical white-head or white-eared plants at maturity. This agrees with the field conditions in so far as white-eared plants occur scattered throughout the crop, but the significant and characteristic feature of take-all is that it occurs in patches where only few plants escape. In the studies reported here the writer attempted to reproduce experimentally the whole range of symptoms, particularly the whitehead condition, in all the plants and in every replication of the treatment.

It was first necessary to eliminate the soil factor alone as a possible cause of the symptoms. The pathogenicity experiments in soils from both take-all and healthy areas demonstrated that the presence of *O. graminis* was necessary for the development of take-all symptoms in plants, and that soil taken from either take-all or healthy sites had no effect on the pathogenicity of the fungus. However, what appeared more important was soil condition as demonstrated by the higher incidence of the disease in cans with dry top soil. This was confirmed in a subsequent experiment where a dry top soil was maintained throughout the growing period of the plant.

In this experiment it was found that all plants in each of the replications with a dry top soil developed symptoms when inoculated with *O. graminis* and all plants that produced ears became whiteheads without exception. These plants were indistinguishable from those affected with take-all in the field; the plants in one of these cans are shown in Fig. 3.

The complete development of take-all in this treatment leaves little room for doubt that at least two primary conditions for the development of the disease are the presence of *O. graminis* and a dry top soil. These conditions would simulate those for the "dry weather take-all" (Russell, 1934), and were those obtaining in the field under observation during the 1940 and 1941 season when studies were made on the ratio of shoot to functioning roots.

The collapse of the plants at any stage of development, but particularly at maturity, might be explained on two grounds, namely, destruction of the roots, and the production of toxic substances by the fungus.

If the production of toxins was responsible for the collapse of the plant, as in vascular wilt diseases, a marked disparity would not be expected to occur between the number of lesioned crown roots on plant, as in vascular wilt diseases, a marked disparity would not during the three seasons reveal that there was a very marked disparity.

Evidence in favour of root destruction would be proportionality in effectiveness of the roots and the load of the shoot system at collapse for plants with different loads. The results for the 1940 and 1941 seasons may be interpreted this way. In the wet spring of 1942, rapid destruction of root tissue subsequent to collapse but before examination, may account for the failure of the season to support the hypothesis. The data in Table 3 show that at maturity all plants had roots with lesions and it was shown elsewhere (White, 1945) that only a percentage of these become white-eared plants. From the writer's findings it seems that whether a plant will be whitehead or normal-eared depends on the capacity of the roots to function above a certain threshold value. This value is affected by the load of the shoot system on the functioning roots and by the moisture available in the soil horizons. The root amputation experiments of Simmonds and Sallans (1929, 1933), and Ludbrook (1942), showed that either seminal or crown roots or both could function in absorbing water from the soil. With the destruction of the seminal roots the crown roots function. When the top soil is dry the surviving crown roots are unable to function and "dry weather take-all" develops as was the case in the writer's experiment. When the top soil is wet then the crown roots could function above the threshold value, provided there were enough of them. Should their development be impaired through the destruction of the root primordia in the crown and first node by *O. graminis* or their rate of destruction exceed their development, then in spite of the wet top soil the functional value of the crown root system will fall below that of the threshold value of the plant concerned with a particular shoot "load." Such a plant will collapse and develop the white-eared condition.

5. Acknowledgment

My sincere thanks are due to Mr. G. A. McIntyre for the biometrical work in this paper and for his helpful criticism during the investigation.

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The Etiology of Take-all Disease of Wheat

4. The Effect of Agronomic Practices on the Incidence and Severity of Take-all

*By N. H. White, D.Sc.**

Summary.

The effect of different agronomic practices on the incidence and severity of take-all disease was investigated in a naturally affected field at Canberra.

It was found that two years' bare fallow resulted in the eradication of *O. graminis* from the soil, as indicated by the complete absence of take-all and freedom from root lesions. Cropping to wheat for four years increased the severity of the disease and decreased crop vigour.

One year's fallow or oats in rotation with wheat, or oats-fallow-wheat rotation decreased the severity of take-all and increased the yield.

General conclusions on the etiology of take-all disease are given.

1. Plan of Investigations

In the previous parts of the study on the etiology of take-all disease in a naturally affected field at Canberra, it was shown that there was a causal relation between *Ophiobolus graminis* Sacc. and the development of take-all symptoms. In order to obtain complementary information on the incidence and severity of the disease different agronomic practices were carried out on the 2-acre block in this field for a period of three years.

The choice of the various treatments was influenced by the reported facts concerning the disease. It has been shown repeatedly that control may be obtained by a one-year break from wheat under oats, any non-cereal crop excluding pastures, or bare fallow. Also that continuous cropping to wheat usually increases the severity of the disease, though some exceptions have been reported (Russell, 1934).

In 1940 the 2-acre area was surveyed into eight equal blocks, each measuring 200 ft. by 50 ft. The following treatments and rotations were applied to each of these blocks respectively:—(i) Wheat followed by fallow, (ii) two years' pasture (ryegrass–subterranean clover mixture), (iii) two years' bare fallow, (iv) two years' lucerne, (v) and (vi) continuously cropped to wheat, (vii) oats followed by fallow, (viii) wheat followed by oats. In 1939 the area was under wheat and the disease occurred in patches over the whole area, as shown in Fig. 2 in Part 1 of this series (White, 1945). In the 1942 season wheat was grown on all the blocks, and data on the following was obtained from each block:—(i) Percentage of take-all, (ii) grain yield per ear, (iii) yield in bushels per acre, (iv) mean height per plant, and (v) mean number of tillers per plant. To determine the percentage of take-all and the numbers of tillers per plant, specimens were examined in 18-in. square quadrats, spaced at staggered intervals in twenty locations in each plot. For determining grain yield per ear, 500 ears were collected at random by walking along five transects spaced equally apart in each block. In each block random samples of plants were taken for examination for root lesions.

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TABLE 1.—THE EFFECT OF AGRONOMIC PRACTICES ON THE INCIDENCE AND SEVERITY OF TAKE-ALL ON WHEAT AT CANBERRA IN THE 1942 CROP.

Plot Number.	1.	2.	3.	4.	5.	6.	7.	8.
Treatments—1940	Wheat ..	Pasture ..	Bare fallow	Lucerne ..	Wheat ..	Wheat ..	Oats ..	Wheat
1941	Fallow ..	Pasture ..	„	„ ..	„ ..	„	Fallow ..	Oats
1942	Wheat ..	Wheat ..	Wheat ..	Wheat ..	Wheat ..	Wheat ..	Wheat ..	Wheat
Percentage of take-all	14·6	2·2	0	13·2	76·4	72·1	3·4	9·7
Grain yield per ear (grams) ..	5·39	1·96	7·63	2·65	1·04	0·84	4·22	3·52
Yield in bushels per acre	30	*Not harvested	38	*Not harvested	*Not harvested	*Not harvested	30	25
Mean height per plant (cm.) ..	46·8	35·6	49·2	37·8	21·0	21·7	46·4	43·3
Mean number of tillers per plant ..	3·07	1·44	4·08	2·15	2·02	2·1	2·83	2·31

* Not enough grain to warrant harvesting.

2. Results

The data for the effect of each of the treatments as revealed in the 1942 season are shown in Table 1.

It will be seen that take-all occurred in all treatments except where bare fallowing was practised for two years (plot 3). The severity of the disease was greatest in the plots continuously cropped to wheat (plots 5 and 6). The occurrence of diseased plants in the two one-year fallow, plots 1 and 7, was noticeably in patches, indicating localized areas of infection. The plants in all plots showing take-all symptoms had variable numbers of roots with lesions. The greatest amount of root destruction occurred in plots 5 and 6 continuously cropped to wheat. All plants examined from the two years' bare fallow, plot 3, showed complete freedom from root lesions.

The well established beneficial effects of fallowing on the vigour and yield of the crops is borne out in the data on the height and tillering, and on yield in plots 1, 3, and 7. Plots 1 and 7 were not kept in the bare-fallow condition and many weeds, including grasses susceptible to *O. graminis,* such as *Hordeum leporinum, Bromus hordeaceus* and *Lolium perenne,* grew on these two plots during fallow. The presence of weeds in these plots served as carrier plants for *O. graminis,* and at the same time reduced the nutritional effects from fallowing. This is reflected in the occurrence of take-all and lower yield in both plots. In plot 3, which was maintained in the bare-fallow condition for two years, the highest yield (38 bushels per acre) of all the treatments was obtained. This appears to be due partly to the eradication of take-all from the soil by starving out the fungus, and partly to the conservation of soil moisture and increase in available plant nutrients through fallowing.

In plots 2, 4, 5, and 6, the crop was so poor that there was not enough grain to harvest. In plot 2, where wheat was sown after two years under ryegrass and subterranean clover pasture, there was too much competition between the ryegrass and wheat from the time of germination until heading out. In plots 5 and 6, continuously cropped to wheat, the two-fold effect of depletion of soil nutrients and the high incidence of take-all was apparent. In addition there was competition from weeds in these two plots. In plot 4, which was under lucerne for two years, the drying of the subsoil and competition from weeds appeared to be the main factors contributing to the failure of the crop on this plot.

3. Discussion

These results provide further evidence that the presence of *Ophiobolus graminis* in the soil is directly related to the occurrence of take-all affected plants. At the same time, the effect of soil fertility on crop vigour in relation to the severity of the disease is apparent.

It is well established that practices inducing high soil fertility, such as fallowing, rotational cropping, and the addition of fertilizers, favour crown root development, which in plants attacked by *O. graminis* would ensure replacement of roots destroyed by fungal attack, and thereby provide the plant with a better chance of survival. No experimental evidence has yet been forthcoming to suggest that

the roots of wheat are immune from attack by *O. graminis*. Furthermore, the writer has frequently obtained evidence which fully substantiates the statement made by Garrett (1938) that "the fungus can attack the most vigorously growing plants, and there is no question of the plant having to be predisposed to the disease by unfavourable conditions."

Therefore, it is concluded that if all the roots of a plant were free from lesions, either *O. graminis* was not present or conditions were unfavourable for the growth of the fungus.

In the two years' bare-fallow treatment reported above, conditions would have been favourable for the growth of *O. graminis*, as shown by the activity of the fungus in the blocks on either side of this treatment. The roots of all the plants examined from this plot were free from lesions. It is assumed, therefore, that the fungus was not present in the soil, and that as a result of the long bare-fallowing treatment the fungus was eradicated. Of all the treatments, the yield and vigour was greatest in the two years' bare-fallow treatment. This result would appear to be due to enhanced soil fertility and conserved subsoil moisture.

Agronomic practices tending to reduce soil fertility such as continuously cropping to wheat, competition from weeds, and low soil moisture would create conditions more favourable to the development of take-all symptoms because these conditions do not favour root development, and attacked plants are unable to replace roots destroyed by the fungus. In the results reported above, soil fertility was lowered in the blocks continuously cropped to wheat for four years, in the treatment under pasture for two years, and in the treatment under lucerne for two years. However, competition for soil moisture was responsible for crop failure in the latter two treatments. In the pasture treatment annual ryegrass was used, and normally seed setting and germination of this crop would have been poor in Canberra because of the dry summer. The 1941–42 summer was a wet one, and resulted in the setting of ryegrass seed and good germination of seed in autumn after the plot had been cultivated in preparation for the wheat sowing of 1942. In the lucerne treatment the complete removal of lucerne crowns was not effected, and the weed population on this plot was high; these competed with the wheat.

In the plots continuously cropped to wheat, take-all was severe and crop failure was due in part to disease and to impoverished soil conditions and competition from weeds.

4. General Conclusions

In the light of the results reported in this series of studies on the etiology of the disease at Canberra, and those reported in the literature, the following conclusions on the incidence and severity of take-all disease of wheat may be made.

The incidence of the disease depends on the presence of the fungus *Ophiobolus graminis* in the soil, and, in turn, the presence of the fungus is related to the previous history of the field. Practices conducive to its persistence in the soil are the continued growing of susceptible crops such as wheat, barley, and certain pasture grasses, and favourable soil conditions such as light-textured soil (Garrett,

1942), and high soil nitrogen content (Garrett, 1944). Practices leading to the disappearance of the fungus from the soil are the growing of non-susceptible crops such as oats, bare-fallowing, and rendering the soil conditions unfavourable by compacting the seed bed (Garrett, 1942), and by increasing biological antagonism through increasing the carbon content of the soil (D'Aeth, 1939).

The severity of the disease is influenced primarily by the capacity of the attacked wheat plant to outstrip root destruction with new root development, and by the distribution of inoculum in the soil. On the one hand, root destruction is influenced by the virulence of the strain of *O. graminis* (White and McIntyre, 1943), which was shown to be genetical in origin (White, 1942), and by the soil conditions affecting the rate of growth and spread of the fungus (Garrett, 1937; Winter, 1939). On the other hand, root formation is influenced by soil fertility, soil moisture, and the surviving crown root primordia. The effectiveness of the balance between destruction of roots and root formation in maintaining the water supply and nutrition to the affected plants depends on the relative rates of root destruction and formation, soil moisture, and the demands of the shoot system on the functioning root system (White, 1947).

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The Treatment of Cut Potato Setts with Zinc Oxide

1. Condition of the setts, growth, and yield

*By J. G. Bald, M.Agr.Sc., Ph.D.**

Summary.

In this and a succeeding paper, an analysis is made of data from a field trial on the effects of treating cut potato setts with zinc oxide before planting. Treatments with water and an organic mercury dip served as controls.

Properly used, the zinc oxide reduced premature rotting of the cut potato setts. It rather encouraged than hindered suberization. Parallel mercury treatments damaged the cut surfaces and allowed rotting organisms to gain entrance to the tuber tissues. In no treatment was there more than 6 per cent. of misses.

The most efficient zinc oxide treatment had no effect on emergence; others slightly retarded emergence. Mercury treatments applied to the cut surfaces seriously retarded emergence.

Zinc oxide treatments had relatively little effect on the leaf area of the plants; mercury treatments caused serious reductions in leaf area. Possibly the slight effects of zinc oxide treatments were partly due to absorption of zinc through the sett.

Zinc oxide treatments had slight effects on the total yield; mercury treatments depressed the yield. Careful analysis suggested that the zinc absorbed through the sett increased the ratio of tubers to foliage, possibly because the soil in which the plants were grown was slightly deficient in zinc. Treatments that encouraged premature rotting of the setts depressed the total yield. Zinc oxide dip efficiently applied increased the over-all growth of the plant by protecting the setts from premature rotting.

1. Introduction

Zinc oxide was found in laboratory trials to act as a protector of the cut surfaces of potato tubers against rotting organisms (Bald, 1943*a*). In contrast to copper compounds, it rather aided than retarded suberization. Dillon-Weston and Taylor (1944) found that salts of manganese, in addition to zinc salts, could be applied to the cut surfaces without adversely affecting suberization. In a South Australian field trial of zinc oxide as a means of controlling missing in potato crops (Beare, 1944), it was incidentally found to give some control of common scab caused by *Actinomyces scabies*. The trial gave no information about missing, because there were few misses amongst the untreated controls.

As a means of protecting cut surfaces of potato tubers in greenhouse and laboratory work, dipping in zinc oxide suspensions and suberization on damp sand have been very successful. In a recent development of experimental methods involving the removal of single eyes with the minimum of tissue from dormant tubers, zinc oxide has again given effective protection of the cut surfaces. The single eyes are dipped in zinc oxide suspension and placed in petri dishes on

* An officer of the Division of Plant Industry.

damp filter paper impregnated with zinc oxide or in trays of damp sand. Even in the saturated atmosphere of the closed petri dish they generally remain clean and turgid, and sprout very rapidly (Fig. 1)*.

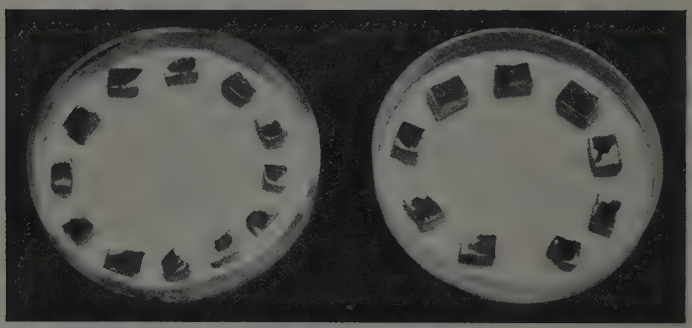

FIG. 1.—Single eyes from potato tubers, treated with zinc oxide and sprouting in petri dishes.

2. Description of the Trial

In the dry spring of 1945, conditions apparently favourable for missing in the potato crops had developed at Canberra. A field trial planted with cut seed pieces was planned to test the effect of zinc oxide on missing, on *Rhizoctonia* infection, with which missing may sometimes be associated, and possibly on common scab. Tubers of the variety Up-to-Date, carrying medium to heavy infection with *Rhizoctonia* and scab lesions, were sorted out from reject material of the previous crop. Tubers as clean and sound as were available, but, unfortunately, not from the same original source, were chosen for an untreated control.

Various treatments with zinc oxide, and an organic mercury compound, were applied to the infected tubers, and the trial was planted on fallowed ground at the C.S.I.R. Experiment Station at Dickson, during the third week of October. The fallowed soil was moister than had been expected after so long a dry period, and within a week of planting 1·4 inches of rain fell. The soil conditions, instead of inducing a high percentage of misses, gave a high percentage of emergence, even in instances where treatment had injured the setts.

The effects of *Rhizoctonia* became evident in the foliage soon after flowering, but a confusion of symptoms was produced by infestation with Rutherglen bug (*Nysius vinitor*) and a severe attack of spotted wilt, both seasonal and unexpected. These prevented records of the incidence of *Rhizoctonia* from foliage symptoms. Fortunately, as the bug infestation and the spotted wilt were distributed over all treatments, they had little effect on the estimation of tuber infection, or on the estimation of infection with common scab. The latter was present on a large proportion of the tubers, and data were obtained for the effects of treatment on both diseases. These are reported in a succeeding paper.

* Mr. D. O. Norris has found sprouting is encouraged by keeping the petri dishes in the dark at a temperature of 25° C.

The sequence of operations and the observations made during the trial were as follows:

October 18.—The treatment of tubers was begun.

October 23, 24.—The trial was planted.

November 9.—The first plants began to emerge.

November 22.—Records were taken of the numbers of plants emerged.

November 28 and 30.—The leaf area of every plant above-ground was recorded (Bald, 1943*b*).

November 29.—Two plants from each of 104 plots were dug, setts were rated for the condition of the cut surface and the extent of rotting; the extent of the lesions on each stem and on the stolons were also noted. The lesions were of the type usually associated with *Rhizoctonia*. Records were also taken of the presence of macroscopically visible runner hyphae on the underground stems and stolons.

January 21.—The leaf area of each plant was recorded as the haulms approached their maximum size.

March 28.—A few plants from all treatments were dug, and the tubers examined for the extent of infection with *Rhizoctonia* and scab, and the type of data that might be obtained from the yields.

April 5–16.—The trial was dug. The haulms were dead, as the growing season had been slightly shortened by an attack of early blight. Thereafter the tubers were sorted, weighed, and examined.

3. Treatments

In all, there were thirteen treatments in the trial. They were:—

1. Clean tubers, cut October 22, setts dipped in water, put in small cloth bags, sufficient in each to plant one plot of the trial. The cloth bags were covered with damp sacks to maintain humidity until the setts were planted during the following two days, October 23 and 24.

2. Infected tubers, cut October 18, setts dipped in water, tipped into open trays and allowed to dry out. The setts lay two to three deep, the cut surfaces frequently in contact with the skin of other setts. On October 22 they were put into small cloth bags, which were covered with damp sacks. A proportion of setts were definitely shrunken after the four days drying.

3. Infected tubers, dipped whole in water on October 18, left in trays until October 22, cut, bagged, protected by damp sacks.

4. Infected tubers, cut October 22, dipped in water, bagged, protected by damp sacks.

5. As for 2, but on October 18 dipped in zinc oxide suspension.

6. As for 3, but on October 18 dipped in zinc oxide suspension.

7. As for 4, but on October 22 dipped in zinc oxide suspension.

8, 9, 10. As for 2, 3, 4, but dipped in an organic mercury fungicide, improved Hortosan.

11, 12, 13. As for 2, 3, 4, but dusted with a zinc oxide-DDT dust.

The zinc oxide suspension consisted of 5 oz. zinc oxide in 1 gallon of water; the organic mercury dip was made up according to directions; and the dust contained 2 per cent. zinc oxide and 1 per cent. DDT in

"pyrophyllite" filler. It was added to the setts in a barrel duster at the rate of 1 oz. to 8 lb. of setts, and the duster was turned until coverage of the setts was complete.

Treatments with the dust were included because zinc oxide had been added to a DDT pyrophyllite dust used by Mr. G. A. Helson in trials on methods for controlling potato moth (*Phthorimaea operculella* Zell.). The zinc oxide largely prevented the rots that normally follow damage by grubs of the potato moth.

The trial consisted of two symmetrical incomplete blocks planted side by side with the rows continuous. There were eight replications of each treatment. Each treatment was a single row 1 chain in length, containing 32 plants equally spaced. At harvest this number had been reduced to a row length of 28, because plants had previously been taken from a strip of 4 across each block. The rows were slightly more than 3 feet apart.

Fertilizer, 6 : 1 superphosphate and ammonium sulphate, was applied in the furrow at the rate of 2 cwt. per acre. The plot was furrow-irrigated twice during the season, on December 17 and January 7. The aggregate amount of water delivered was approximately 4 inches. The rainfall was more regular than is usual during that period of the year; the aggregate between digging and planting was 12·4 inches. There were the usual hot summer temperatures and drying winds.

4. Examination of Setts

(i) *Description of Material and Rating Methods.*

On November 29 and 30, five weeks after planting, two plants in each of the 104 plots of the trial were dug, and the setts, underground stems, and stolons were examined. The setts were present on all plants; some were sound and some rotting.

The main shoots of the plants were still extending; at the top of some of them young buds could be seen in the terminal rosette of leaves. Stolons were growing out, and the underground stems were sappy and firm.

The condition of the sett on each sampled plant was classified according to the following categories:

1. Cut surface firm, clean, and well suberized.

2. Cut surface firm, but suberization relatively poor, giving evidence of fungal growth. Sometimes the surface was covered with a corky, powdery layer of dead tissue permeated by fungus hyphae.

3. Cut surface pitted, often at the edge, and rot beginning.

4. Rot well established.

It was found that the first class might have been subdivided according to the solidity and freshness of the suberized surface. The condition of most setts treated with zinc oxide the day before planting (treatment 7) was distinctly better than any of the others. This does not appear from the rating values. The second rating class was also heterogeneous. It included setts on which extensive chemical injury to the cut surface had killed the tissues to a depth of 5 mm., and tubers of which the suberized layer was merely discoloured and easily rubbed off. There were various intermediate stages of injury and inefficient suberization.

A value of 1, 2, 3, or 4 was given to each sett according to the category into which it fell. Values for the two setts dug from each plot were added, and with this sum as a plot total a full analysis of differences in the condition of the setts was made. The treatment means, halved to give average ratings for a single sett, are in Table 1. Beside them are the actual numbers of setts in each of the four rating classes. Also in this table are those portions of the rating totals represented by tubers in which rots were actually present, i.e. tubers that fell into classes 3 and 4.

A mean rating of 1 for all setts sampled from a treatment would imply that every one of the 16 setts was perfectly sound, with no obvious sign of fungal growth on the cut surface. A mean of 4 would imply that every one was rotting and the rot was well advanced.

TABLE 1.—CONDITION OF THE SETTS SAMPLED FIVE WEEKS AFTER PLANTING.

Treatment.		Number of Setts Rated—				Mean Rating, Single Sett.	Sum of Ratings Rot Only.
Description.	Number.	1.	2.	3.	4.		
Clean setts	1	13	3	0	0	1·20	0
Infected setts, no treatment	2	8	2	2	4	2·15	22
	3	7	3	3	3	2·08	21
	4	7	8	1	0	1·69	3
Infected setts, zinc oxide dip.	5	7	1	5	3	2·19	27
	6	8	5	3	0	1·70	9
	7	16	0	0	0	1·04	0
Infected setts, mercury dip.	8*	0	8	4	4	2·78	28
	..	(0, 0)	(1, 7)	(4, 0)	(3, 1)		
	9	11	4	1	0	1·34	3
	10	2	13	1	0	1·92	3
Infected setts, zinc oxide-DDT dust	11	6	1	3	6	2·54	33
	12	9	3	2	2	1·83	14
	13	9	3	1	3	1·85	15
Significant difference	..	..	..	..	..	0·77	10·6†

* Duplicate ratings for treatment 8 in the two main blocks of the trial.
† Difference does not apply to mercury treatments; see text.

(ii) *Controls.*

Treatment 1, clean setts treated only with water (called hereafter untreated setts) had no evidence of rot, and very little of fungal growth on the cut surfaces of the setts. By contrast, the controls carrying *Rhizoctonia* sclerotia and scab lesions (2, 3, 4) had higher ratings, i.e. significant numbers of setts with evidence of fungal action on the surfaces, or actual rotting. Although there was not the full range of methods of application among the controls planted with clean setts, this contrast suggests that much of the infection may have been tuber-borne and did not arise from the soil.

Throughout the following discussion it is assumed that a large proportion of the organisms causing rotting of the setts was derived from tuber-borne infection. The rotting invariably began from the cut surfaces. Apparently the exposed tissues provided suitable and convenient sites for the growth of organisms originally carried externally on the skin of the tubers. No assumption is made about the identity of these organisms, but it seems likely that strains of *Rhizoctonia solani* were among those causing damage to the setts.

The comparisons between treatment 4 and treatments 2 and 3 reveal interesting differences in the condition of the setts. The mean rating of 1·69 for setts in treatment 4 was mainly due to a rating of 2 for 8 of the 16 setts. On these 8 setts suberization had been obstructed by organisms that had invaded the cut surface, but up to the time of sampling the suberized cells had been an effective barrier against actual rotting. Suberization had been just sufficiently rapid to protect the underlying tissues. On only one sett had it been ineffective.

In treatments 2 and 3 approximately the same number of setts gave evidence of obstruction to suberization by invading organisms as in treatment 4, but in each of treatments 2 and 3, 6 setts were definitely rotting, as against 1 in treatment 4. Although the mean ratings for setts in the three treatments were not significantly different, the differences between those portions of the rating totals contributed by setts that were actually rotting were clearly significant (see last column of Table 1). The differences between these ratings for treatments 4 and treatments 2 and 3 were 19 and 18, and the minimum significant difference was 10·6.

The operation that appeared to give this advantage to the setts in treatment 4 was the wetting of the cut surfaces and the maintenance of high humidity around the setts until they were planted. The setts in treatment 2 were also dipped in water, but were allowed to dry out for 4 days before planting. Those in treatment 3 were cut the day before planting, and kept under moderately humid conditions, but were not wetted.

(iii) *Zinc Oxide Dip.*

Of the treatments in which the setts or tubers were dipped in a suspension of zinc oxide, number 7, dipping of the cut setts the day before planting, completely prevented premature rotting. It gave the cut surfaces an extra firmness and solidity, and there was practically no evidence of obstruction to suberization from fungal activity. This treatment had no discernible effect on emergence, although the zinc oxide dipping and dusting treatments as a whole caused a slight delay in emergence. The growth of the plants in treatment 7 was as good as in any other treatment (Tables 3A, 3B).

When the zinc oxide dip was applied to the setts after cutting, and they were allowed to dry out for 4 days, it gave no protection against rotting (compare treatments 5 and 2). Applied only to the whole tubers, it gave the setts cut from them some protection (treatment 6). Although the mean rating for treatment 6 was not significantly less than for the corresponding control (treatment 3), the sum of ratings for only those setts in which rot was present was

significantly less (last column, Table 1). As in treatment 4, suberization in most instances more than kept pace with fungal invasion, even though on 5 of the 16 setts there was evidence of some fungal growth and destruction of surface cells (five setts were rated 2).

(iv) *Organic Mercury Dip.*

The mercury treatments produced a different picture. The setts of treatment 8 were badly shrunken and discoloured when they were planted; and, when the sampled plants were dug 5 weeks later, every one showed evidence of chemical injury. The cut surfaces carried a superficial layer, sometimes 5 or 6 mm. thick, of brown powdery dead tissue permeated by the mycelia of saprophytic fungi. The surface of the solid tissue below was brown, and carried no properly suberized layer. Possibly the main barrier against rotting organisms on those setts was the antagonistic action of the saprophytic organisms in the dead tissue; certainly normal barriers were almost absent.

This resulted in a condition of instability which was reflected in the duplicate rating totals for the two main blocks of the trial (Table 1, treatment 8, figures in brackets). Although only distances of 4 to 12 feet separated sampled plants in the two blocks, the line of division between the two blocks was also, along much of its length, the approximate boundary between two soil types. The soil of one main block was a clay loam, of the other a clay loam mixed with a high proportion of gravel. Of the eight setts of treatment 8 dug from the former soil, seven were rotting. Of the eight setts dug from the gravelly soil, only one was rotting. There is little doubt this variability within the same treatment represented a real difference between blocks in the reaction of the setts. Changes in soil conditions that did not affect the incidence of rot in setts from other treatments affected it in this one.

An incidental result of this instability was that the values for the mercury treatments were discarded from the estimate of the standard error for the rating totals, rotted tubers only. Hence the significant difference, 10·6, is not applicable to comparisons involving the mercury treatments. It is probable, however, that the condition of setts in treatment 9 was better than in the corresponding control (3). The difference between the mean ratings for 3 and 9 was almost at the 1 in 20 level of significance. There can be no doubt that the poor condition of the setts in treatment 10 was due largely to chemical injury.

Chemical injury to the setts in treatments 8 and 10 was followed by delayed emergence and a reduction in size of the plants, particularly in treatment 10. The high humidity maintained after the setts in treatment 10 were dipped apparently enabled the absorption of greater quantities of mercury at the cut surface.

The mercury dip, applied to whole tubers, which were then allowed to dry out before cutting (treatment 9) improved the condition of the sett in comparison with the corresponding control, treatment 3, but it cannot be considered so efficient for this purpose as treatment 7. Although the difference between treatments 7 and 9, as shown in Table 1, is not significant, the qualitative differences in the condition of the setts, that found no expression through the rating scale, were in favour of this zinc oxide treatment.

(v) *Zinc Oxide–DDT Dust.*

The application of the zinc oxide-DDT dust did nothing to improve the condition of the setts. The ratings for these treatments (11, 12, 13) were no less than those for the corresponding controls (2, 3, 4), and the ratings for rotted setts only were significantly higher than those for the corresponding zinc oxide treatments (5, 6, 7). Only the treatment in which the dust was not put directly on the cut surface remained free from this effect. In that one (12) the sum of the ratings for rotted tubers only was not significantly different from either the corresponding zinc oxide dip treatment (6) or the corresponding control (3).

The dust probably acted by withdrawing water from the cut surfaces of the setts and hindering rapid suberization, without preventing the entry of rot organisms. That dusted setts rapidly lost water was evident from the condition of the setts in treatment 11, four days after cutting and dusting. They were as badly shrunken as the setts of the corresponding mercury treatment (8), although the surfaces were not as seriously discoloured.

(vi) *Summary.*

Rapid and efficient suberization appeared, under the conditions of this trial, to be essential for the prevention of premature rotting. A sufficient and continuous water supply to the exposed cells of the cut surfaces was absolutely necessary for efficient suberization. Wetting the cut surfaces and the maintenance of humid conditions until planting in damp soil gave these cells the water they needed. Also it may have encouraged the growth of organisms which found their way from the skin of infected setts to the cut surfaces of others in contact with them, or grew over the edge of the cut surface from the skin of the same sett. In spite of this invasion, rapid and efficient suberization in most instances gave the underlying tissues of treated setts sufficient protection from fungal attack.

The role of the zinc oxide appeared to be fungistatic rather than fungicidal. Under humid conditions it discouraged the growth of rotting organisms sufficiently to allow full suberization. Under conditions of insufficient water supply to the cells of the cut surface, zinc oxide gave little or no protection. It may possibly have retarded suberization by encouraging the loss of water from the exposed cells, but in the presence of sufficient water it rather encouraged than discouraged suberization. There was no evidence that it had any toxic action on the potato tissue.

Under similar conditions the organic mercury dip, improved Hortosan, was toxic to the cells of the potato tuber, and probably also to the rotting organisms. For this reason, applied to whole tubers, it gave some protection to the setts cut from them, without noticeably affecting suberization, but its effect on the cut surfaces was to destroy many layers of cells, and its absorption seriously affected the emergence and subsequent growth of the potato shoots.

5. Emergence

The emergence data are in Table 2. These are the actual numbers of plants above ground on three dates, November 22, 13 days after the first shoots were observed breaking through the soil, and on November 28 and January 23, when leaf area ratings were made. On November 22, 247 plants had emerged from the 256 setts planted in treatment 1 (97 per cent.). Emergence for the corresponding control with infected seed (treatment 4) was similar. The zinc oxide treatments (5, 6, 7) and (11, 12, 13) on the whole were slightly behind the untreated controls (1 and 2, 3, 4). The treatments in which the cut setts were treated with the mercury dip were considerably behind (8, 10). The most severely affected was treatment 10, in which the cut setts were dipped the day before planting began, and remained under humid conditions until they were planted. Allowing the setts to dry out after dipping (8) caused less retardation of emergence, but finally about the same proportion of misses (6 per cent.).

Apart from the mercury dip series, timing of the treatments had slight but uniform effects. When the tubers were dipped or dusted the day before planting and kept under moist sacks, they sprouted most promptly. The slowest to emerge were those dipped or dusted whole, left for 4 days, and cut the day before planting. Those cut and treated several days before planting were intermediate.

TABLE 2.—NUMBERS OF PLANTS EMERGED ON THREE DATES, FIVE WEEKS AFTER PLANTING; WHEN THE FIRST LEAF AREA RATING WAS MADE; AND AT MATURITY WHEN THE SECOND LEAF AREA RATING WAS MADE.

Treatment.	Number of Plants.		
	November 22.	November 28.	January 23.
1	247	252	256
2	238	249	251
3	234	248	253
4	243	255	256
5	229	245	247
6	226	248	251
7	237	246	252
8	179	229	239
9	214	245	251
10	93	184	240
11	227	248	249
12	219	241	247
13	233	246	248

6. Leaf Area

The results of rating for leaf area are in Table 3. Each plant was rated according to an established scale (Bald, 1943*b*). The ratings within each plot were added without conversion to actual areas, and the total plot ratings were used as the unit for analysis. No direct allowance was made for missing plants.

The plot totals were very nearly proportional to the logarithms of the total leaf area of each plot. Comparing increments of leaf area ratings over a period of time was more nearly equivalent to a

comparison of growth rates than of increments in leaf area. It was for this reason, and to eliminate the labour of converting the ratings to areas, that summed ratings were used for analysis.

The means for treatments in Table 3 show significant differences. The plants in treatment 1, following rapid emergence, gave the highest values for leaf area on November 28, but not on January 31. This is a reflection of the difference in the source of seed tubers used to obtain clean setts for treatment 1 (p. 88): the difference is evident throughout the growth and yield data. It affected all comparisons with treatment 1 involving growth and yield, but not those that were confined to the incidence of disease. It arose from the early maturity of the only Up-to-Date clone of which clean tubers were available when the zinc oxide trial was planned. The discard Up-to-Date tubers used for treatments 2-13 were unlabelled, and their exact origin was unknown, but they were found from the results of the trial itself, to be derived from later maturing clones. Care was taken to mix the tubers assigned to these 12 treatments very thoroughly before they were divided into single lots.

TABLE 3A.—LEAF AREA, NOVEMBER 28. MEAN TOTAL RATINGS FOR SINGLE PLOTS.

Tr.	Leaf Area.	Tr.	Leaf Area.	Tr.	Leaf Area.	Tr.	Leaf Area.	Tr.	Leaf Area.	Mean Leaf Area.
..	..	2	188·4	5	186·5	8	129·9	11	169·1	168·5
..	..	3	204·1	6	196·0	9	184·2	12	182·7	191·8
1	227·7	4	209·4	7	210·8	10	83·8	13	193·3	174·3
	Mean leaf area		200·6		197·8		132·6		181·7	
	Significant difference between two treatment means							..	..	16·0

TABLE 3B.—LEAF AREA, JANUARY 23. MEAN TOTAL RATINGS FOR SINGLE PLOTS.

Tr.	Leaf Area.	Tr.	Leaf Area.	Tr.	Leaf Area.	Tr.	Leaf Area.	Tr.	Leaf Area.	Mean Leaf Area.
..	..	2	489·5	5	474·8	8	397·8	11	458·8	455·2
..	..	3	502·1	6	484·3	9	470·5	12	471·1	482·0
1	493·2	4	526·0	7	510·1	10	359·7	13	493·9	472·4
	Mean leaf area		505·9		489·7		409·3		474·6	
	Significant difference between two treatment means							..	..	28·7

In spite of the slight lag in emergence, the plants in the zinc oxide dip series (5, 6, 7) were not significantly smaller either on November 28 or January 23 than the controls (2, 3, 4), although on January 23 the difference was close to significance. The zinc-oxide-DDT dust treatments (11, 12, 13) caused a slight but definite reduction in leaf area. The mercury treatment, 9, in which tubers were treated whole and left 4 days before cutting, gave almost exactly the same leaf area values as the corresponding zinc-oxide-DDT dust treatment (12). The other two mercury treatments 8 and 10, particularly 10, had by far the lowest leaf areas on November 28. The leaf areas reflected the delay in emergence caused by treatment of the cut surfaces. The difference was reduced, but by no means eliminated, on January 23.

There were other effects on leaf area than those resulting from delayed germination. To disentangle them from the available data was difficult. The effects of delayed germination were not easily defined or computed, as they were probably both direct and indirect. Firstly the growth cycle as a whole was shifted in time, and this may have had secondary effects on the ultimate size of the plants. There were small differences, up to 6 per cent., in the numbers of plants finally emerging, and there were the unpredictable results of Rutherglen bug invasion, infection with spotted wilt, etc. The bugs, for example, appeared to attack and injure young plants more severely than old, causing more damage to late-emerging plots, and probably inducing differences between treatments in growth rate.

The most practicable objective method of obtaining an estimate of treatment differences, freed from the effects of differential germination, was the use of regressions for leaf area on the emergence count of November 22. The results can be used only as a guide to what may have happened, not as convincing evidence of what did happen. It is possible that under- or over-correction of particular treatment means might produce differences between the estimated values that did not exist in fact.

The relation between leaf area and emergence was close, but not linear. Regressions of the form

$$Y = a + bx + cx^2$$

were calculated for, (1) leaf area, November 28, on emergence counts, November 21, and (2) leaf area, January 23, on emergence counts, November 21. The regression equations were used to estimate what the leaf areas would have been if all treatments had germinated at the same time. The variance of the estimated values was less than that of the unmodified values; but no figure for significant differences is given, for fear of surrounding the results with a spurious air of certainty. The estimated treatment means are in Table 4, presented in the form of deviations from the calculated regression curve. Negative values were below, positive values above the curve.

In this table are also the mean values for the four complete series of treatments, and the means for the three different methods of application or timing. Tratment 1 was omitted from the calculation of the means. Means of several treatments are less likely than means for single treatments to have been distorted by under- or over-correction, so discussion will be confined to them.

TABLE 4A.—LEAF AREA, NOVEMBER 28, ESTIMATED FOR CONSTANT EMERGENCE. VALUES GIVEN AS DEVIATIONS ABOVE OR BELOW THE REGRESSION CURVE FOR LEAF AREA AND NUMBER OF PLANTS EMERGED BY NOVEMBER 21.

Tr.	Leaf Area.	Tr.	Leaf Area.	Tr.	Leaf Area.	Tr.	Leaf Area.	Tr.	Leaf Area.	Mean Leaf Area.
..	..	2	−55·0	5	−17·6	8	−15·9	11	−74·6	−40·8
..	..	3	36·3	6	36·0	9	36·9	12	16·8	31·5
1	29·0	4	−8·9	7	22·5	10	3·3	13	−8·7	2·1
	Mean leaf area		−9·2		13·6		8·1		−22·2	

TABLE 4B.—LEAF AREA, JANUARY 23, ESTIMATED FOR CONSTANT EMERGENCE. VALUES AS ABOVE.

Tr.	Leaf Area.	Tr.	Leaf Area.	Tr.	Leaf Area.	Tr.	Leaf Area.	Tr.	Leaf Area.	Mean Leaf Area.
..	..	2	−40·8	5	−41·1	8	−59·4	11	−88·5	−57·5
..	..	3	96·7	6	18·1	9	23·8	12	8·3	36·7
1	−121·7	4	55·9	7	125·3	10	12·3	13	11·6	51·3
	Mean leaf area		37·3		34·1		−7·8		−22·9	

Methods of application had considerable effects on the growth of the haulm. Throughout the period of growth represented by the two leaf area ratings, the treatments in which the tubers were cut, and the setts then treated and allowed to dry out for 4 days (2, 5, 8, 11), resulted in smaller haulms than those in which the setts were cut and treated just before planting (4, 7, 10, 13). The other method of application, in which the whole tubers were treated before the setts were cut (3, 6, 9, 12), produced at an early stage larger haulms (Table 4A), and at a later stage smaller haulms (Table 4B) than treatments 4, 7, 10, 13. There was here a suggestion that conditions induced in a sett by treatment affected the growth rate of the plants as well as the germination, possibly because they affected the ratio between the tops and tubers. The means for groups of three treatments suggested smaller but similar variations in size and growth rate. This matter will be discussed again in a later section. In the meantime, it is clear that more vigorous growth as well as better germination was obtained from treatments which left the setts fully turgid and well suberized at planting.

7. Total Yield

The yield of the trial as a whole was fairly high, about 9 tons per acre, but the tubers produced were far below commercial standard. The incidence of spotted wilt, the check to growth induced by Rutherglen bug, scab, *Rhizoctonia,* and some injury from the potato moth all reduced the proportion of the better grade tubers. The defects in quality, however, did not affect the comparisons between total yields for different treatments.

TABLE 5.—TOTAL YIELD. TREATMENT MEANS IN LB. PER PLOT.

Tr.	Yield.	Tr.	Yield.	Tr.	Yield.	Tr.	Yield.	Tr.	Yield.	Mean Yield.
..	..	2	77·4	5	79·1	8	56·9	11	70·4	71·0
..	..	3	81·6	6	82·3	9	73·7	12	76·1	78·4
1	77·2	4	85·4	7	87·0	10	52·3	13	81·6	76·6
	Mean leaf area		81·5		82·8		61·0		76·0	
	Significant difference between two treatment means									7·25

These are summarized in Table 5. Because of the different origin of the seed tubers used for the setts of treatment 1, the yield was below that of the corresponding control planted with infected setts (4). The zinc oxide dip treatments (5, 6, 7) taken together gave a mean yield very similar to that for the controls (2, 3, 4); the zinc oxide-DDT dust caused a slight reduction in total yield (11, 12, 13), and the mercury treatments caused a greater reduction (8, 9, 10). Of the three mercury treatments, those in which the cut setts were treated (8, 10) yielded 28 and 40 per cent. less than the corresponding controls. The reduction due to treating whole tubers with the mercury dip before cutting (9) was significant, but only 10 per cent.

The reductions in yield could in a large measure be traced back to retarded germination, but probably also the nature of the treatment and the condition of the setts had an influence on yield independent of germination. In the values for total yield and leaf area at maturity (Tables 5 and 4B) there are indications that plants from setts treated with zinc oxide yielded somewhat better than plants of similar mean size amongst the control and mercury treatments. In Fig. 2, yield is plotted against leaf areas on January 23. A freehand curve is drawn through the values for mercury treatments and controls. All values for zinc treatments are above this line, and the mean difference between the six zinc treatments and points on the curve representing the same values for leaf area appears to be well beyond the 1 in 20 level of significance.

There was apparently not the same balance between the production of foliage and tubers in the zinc treatments and the controls. Amongst plants with equivalent leaf area on January 23, those treated with

zinc oxide produced greater yields than the infected controls, but on the whole their leaf area was probably less. The mean reduction in leaf area below the controls (2, 3, 4) of the zinc oxide dip series (5, 6, 7) was 16·1, and the difference necessary for significance was 16·5. Both yield and leaf area of the zinc oxide-DDT series were less. The basic cause of these variations is not clear from the figures. The difficulties of disentangling the effects of interacting variables has already been mentioned in the section on leaf area. Similar methods as were described there may be used, with the same reservations, to analyse the parallel differences in leaf area and yield, and the possible reasons for them.

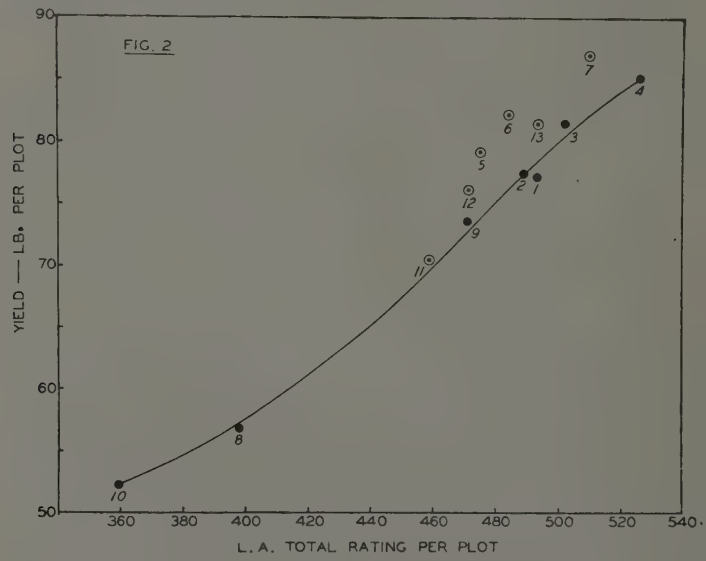

FIG. 2.—Mean total yield for 13 treatments plotted against maximum leaf area ratings. A freehand curve is drawn through the points for untreated controls (1, 2, 3, 4) and mercury treatments (8, 9, 10). Points for zinc oxide dip treatments (5, 6, and 7) and zinc oxide-DDT treatments (11, 12, and 13) are above the curve.

First of all, partial correlation coefficients were calculated between the leaf area ratings, November 28, and leaf area ratings, January 23. Both emergence and the square of emergence were eliminated from the coefficients because of the non-linear relations between emergence and leaf area. The partial correlation coefficient (0·5993) was significant, but much below the simple correlation, 0·9403. Independent of the effects of unequal emergence, there was some tendency for treatments in which the plants were small on November 28 still to contain small plants on January 23. The relative weakness of this underlying association suggests variations between treatments in growth rate during the intervening period. Even apart from the results of unequal emergence, the effects of treatment on the growth and development of the haulms were probably complex.

The association between leaf area on January 23 and yield was not so strongly affected by differences in emergence as that between leaf areas on November 28 and January 23. There was a very strong association, for treatment means within blocks, between leaf area on January 23 and yield ($r = 0{\cdot}9667$, $n = 24$). The association was reduced, but not so greatly reduced as that between the two leaf area ratings, by eliminating the effects of unequal emergence ($r = 0{\cdot}8611$). There was also a high degree of association between yields and the earlier leaf area ratings (November 28): how far this was dependent on unequal emergence was not tested.

These results may be interpreted as follows: Apart from the effects of unequal emergence the main effect of treatment was on the size of the plant as a whole. In addition, the ratio between haulms and tubers was probably affected. There was a close association between leaf area and yield, but not so close as to eliminate a reasonable chance that treatments had an effect on the ratio between the two.

8. Direct and Indirect Effects of Treatment

The possible effects of treatment outlined above were pursued by an extension of the analytical methods already adopted, and the results were put in graphical form. The effects of differential germination, the unwanted variable, were eliminated as far as possible from the yields as well as from both leaf areas by a regression equation of the second degree. The original criticism of this method still applies, that the estimated values for leaf area and yield may not have been consistently and adequately corrected for differential germination.

In Table 6 are the estimated mean yields for the 13 treatments, presented as deviations from the curves of the appropriate regression equations. The estimated values for leaf areas on November 28 and January 23 are in Tables 4A and 4B.

TABLE 6.—TOTAL YIELD, ESTIMATED FOR CONSTANT EMERGENCE. VALUES GIVEN AS DEVIATIONS ABOVE OR BELOW THE REGRESSION CURVE FOR YIELD ON NUMBER OF PLANTS EMERGED BY NOVEMBER 21.

Tr.	Yield.	Tr.	Yield.	Tr.	Yield.	Tr.	Yield.	Tr.	Yield.	Mean Yield
..	..	2	−13·2	5	5·9	8	−22·4	11	−25·6	−13·8
..	..	3	11·5	6	23·1	9	1·4	12	7·2	10·8
1	−33·9	4	8·7	7	22·2	10	4·3	13	10·8	11·5
	Mean yield ..		2·3		17·1		−5·6		−2·5	

To obtain an accurate estimate of the relation between leaf area and yield, it would be necessary to integrate the leaf area over the period when tuber formation occurred. A crude approximation to such integration, useful for comparison between treatments, is the mean of the estimates for the two leaf area ratings. One of these was made at the inception of tuber formation, the other when the

plants were at or near their maximum size. Estimated yields were plotted against the mean of estimated leaf area ratings (Fig. 3), and below them were plotted the ratings for the condition of the setts (Table 1).

In Fig. 2, values for yield were plotted against leaf area on January 23 without eliminating the effects of unequal emergence, and the yields of the zinc oxide treatments were higher for equivalent leaf areas measured at that time. In Fig. 3 such differences appear more clearly defined. All treatments are within a relatively small range of estimated leaf area values, and the yields for the three methods of application within each main treatment fall about a curve that appears to be placed on a level characteristic for that treatment. The most interesting, and probably the most valid comparison is between the zinc oxide dip series (5, 6, 7) and the untreated controls (2, 3, 4). Points for the former occur uniformly above the latter, and correspondence in form between the curves drawn through the two sets of points is very close. Similar curves are drawn through the less regular series for the mercury dip and the zinc oxide-DDT series.

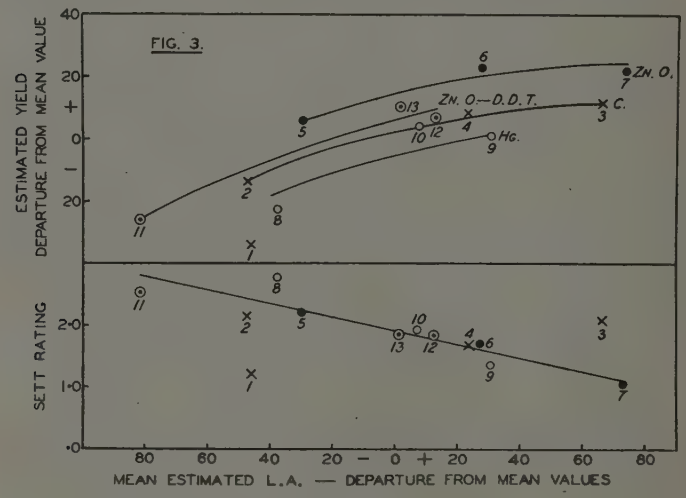

FIG. 3.

Of plants with the same mean leaf area during the period when tubers were forming, those growing from setts treated with the zinc oxide dip (5, 6, 7) produced a higher yield of tubers than those of the controls (2, 3, 4). Presumably zinc was absorbed by the treated plants in sufficient quantity to alter their metabolism. Those treated with zinc oxide-DDT dust (11, 12, 13) may have absorbed lesser amounts of zinc, which had effects so slight as to be of doubtful significance.

The lowering of yield for equivalent leaf area in the mercury treated series might be an artefact due to the degree of correction needed to bring the values to equal emergence. Against this view is

the position of the point for treatment 9; the correction needed to equalize for emergence in this instance was not great. If the difference between the mercury and control series was real, it would imply that the presence of a mercury compound on the setts decreased the efficiency of the plants growing from them in the production of tuber tissue—an effect opposite to that of zinc oxide.

The value for treatment 1 was below those for plants of similar leaf area in all other treatments, presumably because the setts were derived from an early-maturing clone of Up-to-Date.

The ratings for the condition of the setts, plotted against leaf area below the estimates of yield in Fig. 3, provide an explanation for the rising curve of yield on leaf area within each set of three treatments. With two exceptions, the sett ratings form a well graded series, falling as the leaf area and yield rise. The sett rating of treatment 1 is abnormally placed because of the origin of the setts. Treatment 3 has a relatively high value for sett rating where a lower one would be expected, but this is insufficient to nullify the general trend.

The indirect effect of treatment on yield may be summarized as follows:—The condition of the setts was modified by treatment. The plants of those treatments in which the setts remained sound and turgid grew more rapidly and produced larger tops than those in which the setts were in poor condition and rotted prematurely. This difference, in turn, was reflected in yields, the larger haulms on the whole producing the greater yields. The simple relation between size and yield, however, was probably complicated by direct effects of treatment on the ratio between haulms and tubers; and both size and yield were subject to the effects of unequal germination induced by treatment.

Even through this screen of disturbing influences it is possible to demonstrate associations between sett ratings and leaf area and sett ratings and yield. Using the 26 pairs of intra-block treatment means, a correlation coefficient of $-0{\cdot}4101$ was calculated for sett rating and leaf area on January 23, and a coefficient of $-0{\cdot}4121$ for sett rating and yield. Exclusion of the values for treatment 1, which were not comparable with those for other treatments, would have raised these coefficients to higher values.

9. Discussion

In this and the following paper, the results of a single field trial on the use of zinc oxide as a disinfectant for cut potato setts are examined in detail. The discovery that zinc oxide might be used to protect the cut surfaces of potato tubers is recent (Bald, 1943*a*). The experiment described here was designed to give a wide range of preliminary information by the collection of parallel data on disease incidence and on the growth of potato plants from treated and untreated setts. The results have been sought by comparison and inference, not by the repetition of experiments and the elimination of unwanted variables. The object has been to outline problems rather than find definitive answers.

The effects of zinc oxide on the condition of the setts and on growth and yield hold a promise of usefulness that warrants further work on its use as a protector of cut potato setts. Given conditions that normally favour suberization on the cut surfaces of tubers, zinc oxide is not toxic to tuber tissue, rather it favours suberization. It is probably fungistatic rather than directly toxic to fungi, and so weighs the balance in favour of the production of sound and healthy setts. It is not likely to compensate for careless methods of preparing cut setts for planting, but it is likely to enhance the efficiency of good methods.

Of the thirteen treatments in the trial, number 7 was the best in its effect on the condition of the sett, growth, and yield. The setts were cut, dipped in zinc oxide suspension, and maintained under humid conditions until planting. This treatment might in practice be more effectively applied, not to infected but to healthy setts. The setts might be cut directly into the zinc oxide suspension without the cut surfaces making contact with the skin of other setts until they were coated with zinc oxide. Also the cutting knife might be regularly dipped into the zinc oxide suspension.

The method of dipping whole tubers in a mercury compound before the setts were cut was not so effective as the best zinc oxide dip. The use of zinc oxide-DDT dust on the whole tubers before the setts were cut gave results similar to those of the corresponding mercury treatment. A more suitable filler than crude pyrophyllite might be found for making up the dust, or zinc oxide-DDT dust without a filler might be used. If control both of infestation with the potato moth and rotting of seed tubers in storage were wanted, as well as protection of the setts, such a dust might be very valuable.

The direct effect of zinc oxide on the growth of treated plants, suggested in Fig. 3, might result from a deficiency of zinc in the soil where the trial was conducted. In other deficient soils, the use of zinc oxide should increase the efficiency of the potato plant for the production of tubers. The direct effect of treatment would not be expected in soils containing plenty of available zinc.

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The Freezing Point of Soil Water in Relation to the Permanent Wilting Percentage

*By C. G. Gurr**

Summary.

The relation between permanent wilting percentage and freezing point depression of soil water was investigated for eight Australian soils, and the results compared with those of other workers.

When the conditions of freezing were suitably controlled, the water content of soil corresponding to a depression of 1·5°C. was found to give a close approximation to the permanent wilting percentage.

The direct method of determining the permanent wilting percentage of soils, as described by Marshall and Williams (1942), requires a period of several weeks in which to grow plants in soil samples and allow them to wilt. An indirect determination can be made through the measurement of the depression of the freezing point of water in the soil. This method has not so far been used with Australian soils, and the present investigation was designed for the purpose of ascertaining the usefulness or otherwise of the method in the case of local soils.

The work of Schofield and Da Costa (1938), and of Bodman and Day (1943), on the energy relations of soil water as determined by the freezing point shows that approximately the same depression is found at the permanent wilting percentage in all soils. This is because freezing point depressions give a measure of the energy with which soil water is held, and the permanent wilting percentage corresponds to a definite value of this energy. This value may be calculated in terms of the free energy of escape of soil water, termed moisture potential, by the equation—

$$\text{moisture potential} = \frac{L\ T}{T_0} \text{ ergs/gram of water,}$$

where L = latent heat of fusion of water ($-3{\cdot}336 \times 10^9$ ergs/g.)

T = freezing point depression of water in soil (°C.)

T_0 = freezing point of pure water (273·18° absolute).

This quantity is numerically equal to an osmotic pressure of $\frac{L\ T}{T_0}$ dynes/sq. cm. or $\frac{L\ T}{T_0 \times 1{\cdot}013 \times 10^6}$ atmospheres.

To test the value of this method, the two procedures of Schofield and Da Costa (1938) were tried. In procedure A the use of three freezing baths gives control over the amount of supercooling, and reduces the effect of further cooling while freezing is taking place. Procedure B is less accurate in that only one freezing bath, at a temperature of about —3°C., is used.

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The heat capacity of the freezing tube containing moist soil and Beckmann thermometer is determined in terms of water-equivalent in both procedures. Then an estimate of the percentage of ice formed during freezing may be calculated from the relation—

$$\text{ice as percentage of oven-dry soil} = \left(\frac{100W}{LS} + \frac{M}{L}\right) \triangle T$$

where W = water equivalent of tube + dry soil + thermometer (grams)

S = dry weight of soil in tube (grams)

$\triangle T$ = rise in temperature during freezing (°C.)

L = latent heat of fusion (calories/gram)

M = water content of soil on oven-dry basis (%).

This estimate in procedure B is too low, owing to cooling during freezing. Early results showed that consistent results could not be obtained, and procedure B was not used further.

The calculated percentage of ice formed is subtracted from the percentage water content of soil on the oven-dry basis, to give the true water content at the measured freezing point.

Freezing point depressions were plotted (Fig. 1) on a logarithmic scale against corrected water content for eight soils (Table 1). On the curve for each soil the value of the permanent wilting percentage, obtained by the direct method, was interpolated to find the freezing point depression corresponding to that percentage. Results, for procedure A, are summarized in Table 2.

TABLE 1.—DETAILS OF SOIL SAMPLES USED.

Sample No.	Location.	Depth.	Clay Content.	Moisture Equivalent.	Total Soluble Salts.	pH.
		in.	%	%	%	
9228	Ord River, W.A. ..	0–9	5·2	3·8	·005	6·7
6398	Waikerie, S.A.	0–17	4·2	4·09	·027	8·8
9218	Ord River, W.A. ..	0–6	12·8	14·3	·008	6·8
6272	Waite Institute, S.A. ..	0–4	17·5	20·6	·039	5·9
4537A	Curlwaa, N.S.W. ..	0–11	33·6	21·0	·021	7·7
3927	Merbein, Vic.	0–7	13·8	16·3	·535	8·6
9224	Ord River, W.A. ..	0–7	50·4	27·4	·020	8·1
4459	Atherton Tableland, Qld.	Surface	31·3	27·8	·102	8·3

TABLE 2.—FREEZING POINT DEPRESSIONS AT THE PERMANENT WILTING PERCENTAGE.

Soil No.	Permanent Wilting Percentage (Direct Method).	Depression of Freezing Point (Method A).
		°C.
9228	1·62	1·4
6398	2·41	1·5
9218	6·24	1·4
6272	6·32	1·4
4537A	9·95	3·1
3927	10·27	1·9
9224	16·33	2·7
4459	19·44	3·1

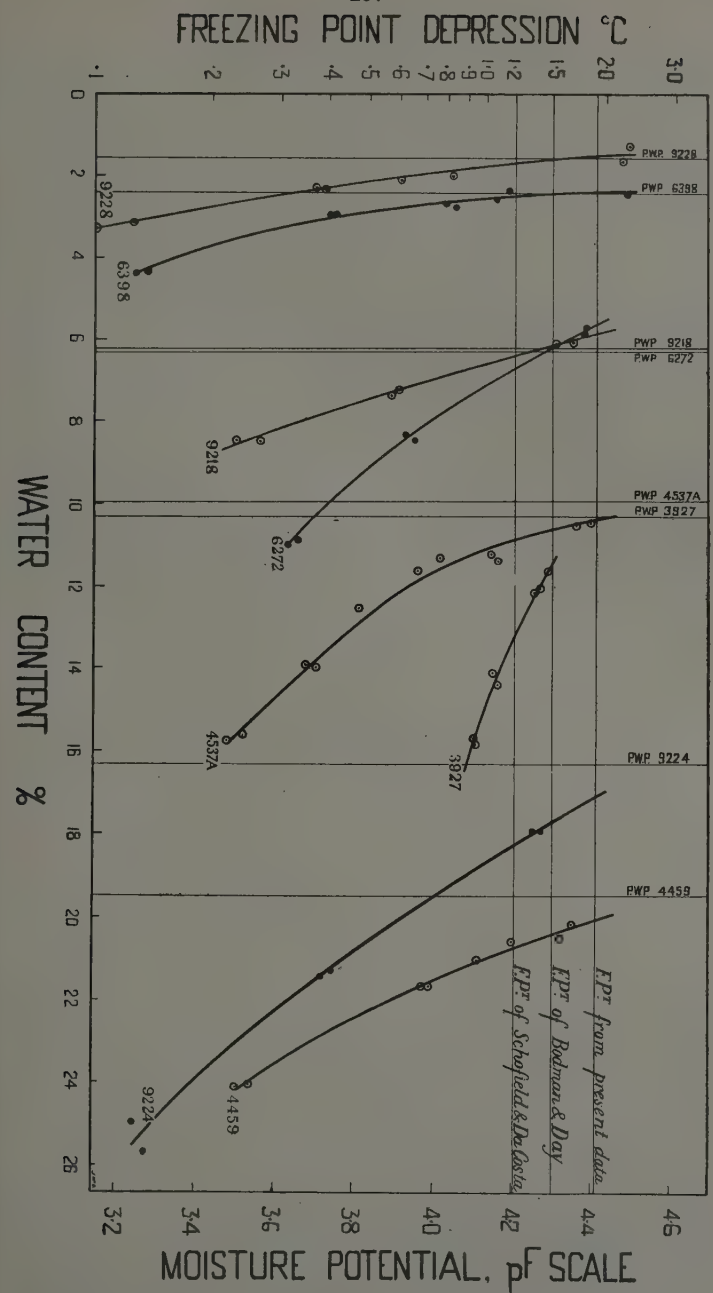

FIG. 1.—The relation between depression of freezing point and water content for eight soils. The permanent wilting percentage (P.W.P.) determined by the direct method is also shown for each soil.

As can be seen in Fig. 1, the freezing point depressions given in Table 1 were in some cases obtained by extrapolation, owing to the difficulty in finding freezing points below about — 2°C. From Table 1 it appears that increasing values of permanent wilting percentage give greater values of depression of the freezing point. However, the data are not sufficient to be conclusive, and this trend is not shown in the results of other workers.

The geometric mean value for freezing point depressions given in Table 1 is 1·9°C. Schofield and Da Costa (1938) give 1·2°C., and Bodman and Day (1943), using a thermocouple method, give 1·5°C. as mean values. In terms of moisture potential at 0°C., these figures correspond to $-23{\cdot}2 \times 10^6$, $-18{\cdot}3 \times 10^6$, and $-14{\cdot}7 \times 10^6$ ergs/gram of water respectively, or as equivalent osmotic pressure, 22·9 18·1, and 14·5 atmospheres respectively. Corresponding pF values (Schofield and Da Costa, 1938) are 4·4, 4·3, and 4·2.

Since the curves of freezing point depressions against water content have in general a steep slope in the region of the permanent wilting percentage, the variation in these mean figures represent only small differences in water content. Consequently, Bodman and Day's figure of 1·5°C., which is approximately the mean of these three figures, will give with reasonable accuracy the permanent wilting percentage of the eight soils used in the present comparison (Table 3).

TABLE 3.—COMPARISON BETWEEN PERMANENT WILTING PERCENTAGE AND WATER CONTENT CORRESPONDING TO FREEZING POINT DEPRESSIONS OF 1·9, 1·5, AND 1·2°C.

Soil Number.	Permanent Wilting Percentage (Direct Method).	Water Contents Corresponding to Depressions of—		
		1·9°C.	1·5°C.	1·2°C.
	%	%	%	%
9228	1·62	1·5	1·6	1·7
6398	2·41	2·3	2·4	2·5
9218	6·24	5·9	6·2	6·4
6272	6·32	5·6	6·2	6·7
4537A	9·95	10·3	10·6	10·8
3927	10·27	10·3	11·5	12·8
9224	16·33	17·1	17·7	18·2
4459	19·44	20·0	20·3	20·5

The influence of salt concentration does not appear to alter the relation. For soil No. 3927 with its high salt content of 0·5 per cent., the curve (Fig. 1) is flattened; but the error in taking the water content at 1·5°C. depression as the permanent wilting percentage is only slightly greater than for the other soils.

Conclusions

The investigation confirms the experience of previous workers that the freezing point method offers a reasonably accurate means of determining the permanent wilting percentage of soils indirectly.

It is necessary for best results that three freezing baths be used in determining the freezing point of soil water, and that heat capacity be determined for estimation of ice formation.

A freezing point depression of 1·5°C. is a suitable basis for assessing the water content corresponding to the permanent wilting percentage.

Acknowledgment

The author wishes to thank Dr. T. J. Marshall for suggestions in preparing this paper.

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C.12900/46—8

A Spectrochemical Survey of Some Phosphate Rocks and Superphosphates

1. Qualitative

By A. C. Oertel, M.Sc., and H. C. T. Stace, B.Sc.**

Summary.

Fifteen samples of phosphate rock and ten samples of superphosphate have been examined spectrochemically. In addition to the major constituents, the presence of 23 other elements is noted with a maximum of 20 in any one sample.

Molybdenum was found in samples of phosphate rock from Egypt, Algeria, and Florida, but not in samples from Nauru and Ocean Island. As supplies of phosphate rock from these latter sources were cut off during the war, the war-time superphosphate contained more molybdenum than the pre-war quality.

Nickel was noted in all samples except those from Ocean Island and Nauru.

Cobalt was found only in samples from Florida, the low-grade phosphate rocks from South Australia, and two superphosphates.

The presence of some of these trace elements should be considered in the interpretation of any field experiments carried out with war-time superphosphate.

1. Introduction

Observations by Professor H. C. Trumble of the Waite Agricultural Research Institute on the apparent differences in response of pastures on Kangaroo Island to pre-war and war-time superphosphates, led to a detailed spectrochemical survey of 29 samples of phosphate rocks, superphosphates, and acid neutralizers. Several investigators (1–8) have examined mixed fertilizers, phosphate rocks, superphosphates, &c., by chemical and physico-chemical means for the "trace" plant nutrients.

Walkley (1) has determined zinc, cadmium, copper, and manganese in Nauru and Ocean Island phosphates and superphosphates manufactured from these sources.

Jacob *et al.* (2) in a survey of the phosphate resources of the United States of America made determinations for magnesium, titanium, sodium, manganese, potassium, &c., while Ballard (8) in a spectrochemical survey of twelve samples of fertilizers, amongst which were two phosphate rocks and two superphosphates, recorded the presence of 21 of the arc-sensitive elements.

This appears to be the first spectrochemical survey of a wide range of phosphates and superphosphates for those constituents which may be detected in the direct-current arc.

2. Experimental

Table 1 gives details of the samples examined. The samples as obtained were either finely divided or in small lumps. In the former case a sub-sample of from 1 to 2 grams in weight was ground in an agate mortar to secure homogeneity; in the latter case a larger

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sub-sample was finely ground in a porcelain mortar, and then the smaller sub-sample was mixed in the agate mortar. Duplicate samples of from 100 to 150 mg. were taken from each sub-sample, and each sample loaded into the cavity of a tared graphite electrode. These large samples were used to reduce the error caused by heterogeneity and to lessen the likelihood of missing volatile components present at low concentrations.

A Hilger Automatic Large Quartz Spectrograph (E 492) was used to record the spectrograms. The slit width used was 10 microns. The samples were arced, using a current of 15 amperes, an arc length of 4 mm., and an exposure of 60 seconds. Ilford Long-Range Spectrum plates were used for the wave-length range from 8000A–3200A and Kodak Process plates for the ranges 3500A–2460A and 2900A–2240A. The last range was photographed for selected samples only, in order to verify the presence of cadmium by the line Cd. 2288A.

To increase the range of concentrations which could be recorded at suitable densities on the plates, the spectrograms were stepped by using a rotating stepped sector of ratio 4. Each plate carried an iron arc spectrogram, stepped by a rotating stepped sector of ratio 2. That spectrogram was used to determine the *H* and *D* curve of the plate for each wave length of interest. The plates were developed for three minutes in 1: 2 metol-hydroquinone developer.

3. Discussion

A complete qualitative analysis, subject to the limitation imposed by the wave-length ranges used, was made of each sample. The results are recorded in Table 1. In that table, M denotes a major component; h, m, and l that the element is present at a concentration of the order of parts per 100, parts per 10,000, and parts per 1,000,000 respectively. The indication of the order of concentration is an estimate only, based on past experience, and may sometimes be in error for the less common elements.

The elements of agricultural interest include iron, manganese, copper, zinc, cobalt, molybdenum, and boron. Of these, it is seen that zinc and molybdenum are sometimes present in superphosphates at concentrations high enough to be important when the fertilizer is used in an experiment on a "deficient" soil. Figures by Walkley (1), who gives for Nauru and Ocean Island rocks 900 and 1,000 p.p.m. respectively, confirm these estimates. He has also shown that the amount present in a superphosphate depends upon the method of manufacture of the acid used in the production of the superphosphate. Superphosphate made with acid manufactured from zinc concentrates by the chamber process may contain as much as twice the amount of zinc as that produced with acids made from elementary sulphur or by the contact process.

In the case of molybdenum, it is of interest that it was detected in ten samples representing three localities: Kosseir, Egypt; Bona, Algeria; and Florida, U.S.A., listed in order of decreasing concentration.

While the amounts found were small—of the order of parts per million—they are perhaps not without significance. Anderson (9) has obtained field responses following the application of molybdenum trioxide at rates as little as 1/16 oz. per acre, which in a 2-cwt. per

TABLE 1.—SHOWING THE PHOSPHATE ROCKS, SUPERPHOSPHATES, AND ACID NEUTRALIZERS EXAMINED, WITH AN ESTIMATE OF THE ORDER OF CONCENTRATION FOR THE ELEMENTS DETECTED.

M = major component, h = parts per hundred, m = parts per ten thousand, l = parts per million.

Description.	Origin.	Element.																						
		Li.	Na.	K.	Rb.	Cu.	Ag.	Mg.	Ca.	Sr.	Ba.	Zn.	Cd.	Al.	Si.	Sn.	Pb.	P.	Sb.	Cr.	Mo.	Mn.	F.	Fe.	Co.	Ni.
Phosphate rock	Nauru	l	m	l	..	l	l	m	M	m	l	m	l	m	m	..	l	M	l	l	..	l	h	m	..	..
,, ,,	Ocean Island	l	m	m	..	l	l	m	M	m	..	m	l	m	m	..	l	M	..	l	..	l	h	m	..	..
,, ,,	Safi, Morocco	l	h	m	..	m	l	m	M	m	l	m	l	m	h	..	l	M	l	m	..	l	h	m	..	l
,, ,,	,, ,, ...	l	h	m	..	l	l	m	M	m	l	m	l	m	h	..	l	M	l	l	..	l	h	m	..	l
,, ,,	Morocco	l	h	m	..	l	l	m	M	m	l	l	..	m	h	..	l	M	l	m	..	l	h	m	..	l
,, ,,	Bona, Algeria	l	h	l	..	m	l	m	M	m	l	l	l	m	h	..	l	M	l	m	l	m	h	m	..	l
,, ,,	,, ,, ...	l	h	m	..	l	l	m	M	m	l	l	l	m	h	..	l	M	l	l	l	l	h	m	..	l
,, ,,	Kosseir, Egypt	l	h	m	..	l	l	m	M	m	l	l	..	h	h	..	l	M	l	l	l	l	h	h	..	l
,, ,,	,, ...	l	h	m	..	l	l	m	M	m	l	l	..	m	h	..	l	M	..	l	l	l	h	h	..	l
,, ,,	Florida, U.S.A.	l	m	m	..	l	l	m	M	m	l	l	..	h	h	..	l	M	..	l	l	m	h	h	l	l
,, ,,	,, ,, ...	l	m	m	..	l	l	m	M	m	l	..	..	h	h	..	l	M	..	l	..	m	h	m	l	l
,, ,,	Kapunda, South Australia ..	l	m	m	..	l	..	m	M	m	m	l	..	h	h	..	l	M	..	l	..	l	m	h	l	l
,, ,,	Hermitage, South Australia ..	l	m	m	l	m	l	m	M	l	l	l	..	h	h	..	l	M	..	l	..	m	m	m	l	l
,, ,,	Truro, South Australia ..	m	h	h	l	m	..	m	M	l	l	m	..	h	h	l	l	M	..	l	..	m	m	h	l	l
,, ,,	Orroroo, South Australia ..	m	m	h	l	l	l	m	M	m	m	m	..	h	h	l	l	M	..	l	..	m	m	h	l	l
Superphosphate	30 per cent. Makatea + 70 per cent. Kosseir	l	m	m	..	l	l	m	M	m	l	l	..	h	h	..	l	M	l	l	l	m	m	h	l	l
,,	50 per cent Makatea + 40 per cent. Kosseir + 10 per cent. Kapunda	l	m	m	..	l	l	m	M	m	l	l	..	h	h	..	l	M	l	l	l	l	m	h	..	l
,,	25 per cent Makatea + 75 per cent. Egyptian	l	m	m	..	l	l	m	M	m	l	l	..	m	h	..	l	M	..	m	l	l	h	m	..	l
,,	45 per cent. Makatea + 55 per cent. Egyptian	l	m	m	..	l	l	m	M	m	l	l	..	m	h	..	l	M	l	l	l	m	m	h	..	l
,,	100 per cent. Bona	l	h	m	..	l	l	m	M	m	l	l	l	m	m	..	l	M	l	l	l	m	m	m	..	l
,,	100 per cent. Ocean Island ..	l	m	l	..	m	..	m	M	m	l	m	l	m	m	..	l	M	l	l	..	m	m	m	..	..
	,, ,, ,, ,, ..	l	m	l	..	l	l	m	M	m	..	m	l	m	m	..	l	M	..	l	..	l	m	m	..	..
,,	Ocean Island + Nauru ..	l	m	l	..	l	..	m	M	m	l	m	l	m	m	l	l	M	l	l	..	l	m	m	..	..
,,	Serpentine Super from New Zealand	l	m	m	..	l	..	m	M	m	l	l	..	m	h	..	l	M	l	m	..	m	m	h	l	l
,,	Special Super (granular) ..	l	m	m	..	l	l	h	M	m	..	l	l	m	m	l	l	M	..	l	..	l	m	m	..	..
Shellgrit ..	.. .. ..	l	m	m	..	l	l	m	M	m	l	..	..	m	h	..	l	..	..	l	..	l	..	m	..	..
Marble ..	Angaston, South Australia ..	l	m	m	..	l	l	m	M	m	l	..	..	m	h	..	l	..	..	..	..	m	..	m	..	l
Limestone sand	South Wallaroo, South Australia	l	h	h	..	l	..	m	M	m	l	l	..	h	h	..	l	..	..	l	..	l	..	m	..	l
,, ,,	North Wallaroo, South Australia	l	h	m	..	l	..	h	M	m	l	..	..	h	h	..	..	..	..	l	..	l	..	m	..	l

NOTE.—B, Ti, V, were recorded in all spectrograms. These elements occur as impurities in the electrodes used, consequently no attempt was made at a quantitative estimate of them.

acre dressing of superphosphate is approximately 10 p.p.m. Trumble and Ferres (10) have noted responses from subterranean clover in pots when using superphosphate prepared from Egyptian and Makatea rocks, compared with superphosphate from Ocean Island.

Cobalt was found in only eight samples, four of which were the low-grade phosphate rocks from South Australia. The others were the two from Florida, a Makatea—Egyptian superphosphate, and the serpentine superphosphate from New Zealand.

Other elements worthy of note are rubidium, which only occurred in the South Australian rocks, cadmium and antimony which occurred in eleven and fourteen of the samples respectively, and nickel which occurred in all the phosphate rocks and superphosphates, except those from Ocean Island, Nauru, and the Special superphosphate.

4. Acknowledgments

Acknowledgment is made of the help given by Dr. C. S. Piper (Senior Chemist, Division of Soils, C.S.I.R.) who suggested the survey.

Thanks are due to Mr. A. T. Hicks of Adelaide Chemical and Fertilizer Co. Ltd. and to Mr. C. A. Abbott of Cresco Fertilizers Ltd. who supplied the samples for the survey.

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The Solubility of Lead Fluoride in Aluminium Fluoride Solutions

*By T. R. Scott, M.Sc.**

The solubility of lead fluoride in solutions of aluminium fluoride, containing up to 17·5 g. AlF_3 in 100 g. of solution, has been determined at 25°C. Consideration has also been given to the variation of solubility with time of stirring, amount of excess hydrofluoric acid present, and temperature. The greatly increased solubility of lead fluoride is ascribed to depression of fluoride ion concentration by the formation of complex alumino-fluoride ions. The solutions formed in this way slowly deposit lead fluoaluminate. The coating of lead fluoride, which normally protects a lead surface against corrosion by hydrofluoric acid, is not formed in the presence of aluminium fluoride solutions and severe corrosion of lead vessels may therefore occur. Suggestions are made for other materials of construction which withstand corrosion by such solutions.

1. Introduction

In the course of experiments on the preparation of aluminium fluoride by the neutralization of hydrofluoric acid with aluminium hydroxide, it was found that the solid aluminium fluoride eventually recovered was grossly contaminated with lead fluoride derived from the lead vessels in which the operations had been conducted. In the presence of hydrofluoric acid such vessels acquire a protective layer of lead fluoride; solutions of aluminium fluoride, however, dissolve this layer and the freshly-exposed lead surface may undergo further corrosion.

Since lead is commonly employed as a material of construction in plants where hydrofluoric acid is used, the solubility of lead fluoride in solutions of aluminium fluoride was investigated. A search of the literature has disclosed no quantitative work on this subject, though Fischer and Thiele (3) have commented on the considerable quantities of lead remaining in solution when acid solutions of aluminium fluoride are neutralized with lead carbonate.

From the solubility determinations it should be possible to decide if lead is ever suitable for use with aluminium fluoride solutions and to suggest other materials better able to withstand corrosion in such media.

2. Experimental Methods

The following factors were found to influence the solubility of lead fluoride in aluminium fluoride solutions:—

(i) Time for which solutions were stirred.
(ii) Concentration of aluminium fluoride.
(iii) Acidity.
(iv) Temperature.

For solubility determinations, a considerable excess of lead fluoride was stirred with aluminium fluoride solutions in monel beakers, using silver-plated copper stirrers. Under these conditions no contamination

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of the solutions by the metals employed could be detected. In the majority of experiments, solutions were maintained at a temperature of $25{\cdot}0 \pm 0{\cdot}1°C$. in a thermostatted bath, although results obtained subsequently showed that accurate temperature control was not necessary.

Solutions of aluminium fluoride were prepared in rubber-lined vessels from Laboratory Reagent aluminium sheet and A.R. hydrofluoric acid. By completing the neutralization overnight with pure aluminium foil, it was possible to obtain solutions having a pH value of at least 4·0. The lead fluoride used was of Laboratory Reagent grade, the pH value of aqueous solutions being 5·3 at 25°C.

The lead content of the filtered solutions was determined by the addition of an excess of sulphuric acid, precipitation of lead sulphate being quantitative in the presence of N-sulphuric acid. The precipitate was washed with dilute sulphuric acid and aqueous ethanol (50 per cent. water) and dried to constant weight at 135°C.

Fluorine was eliminated from a suitable aliquot of the filtrate by evaporation to dryness and digestion with concentrated sulphuric acid, after which the aluminium content was determined by precipitation with 8–hydroxyquinoline, as described by Mellan (5).

Solutions of aluminium fluoride are metastable at the concentrations used in these experiments and slowly deposit β–$AlF_3 . 3H_2O$(2). No useful purpose could therefore have been served by analysis of the solid residues obtained in the stirring runs, since equilibrium conditions were not attained. The aim of the investigation was rather to determine the maximum amounts of lead fluoride dissolved under varied conditions, and this maximum was reached quite rapidly, as will be shown later.

3. Experimental Results

(i) *Time of Stirring.*

Preliminary stirring runs, to determine the time required to reach the maximum solubility of lead fluoride, disclosed that the solutions are frequently supersaturated with lead fluoaluminates, which slowly deposit on the sides and bottom of the containing vessel to form an adherent coating. In contrast to pure concentrated solutions of aluminium fluoride, which require nine months to come to equilibrium at 25°C. (2), the solutions containing lead fluoride deposit the major part of the lead as fluoaluminates within 24 hours, the actual time depending upon the concentration of the solutions. The maximum solubility for lead fluoride is reached in 60–80 minutes for solutions containing more than 10 per cent. aluminium fluoride, but the time is decreased to fifteen minutes or less with more dilute solutions. At each concentration of aluminium fluoride, therefore, samples were drawn from the vessels at frequent intervals, and the maximum solubility chosen from the analytical results. Under such circumstances, it is possible that the absolute maximum value was not always obtained, and this source of error is apparent in Fig. 1; from the same figure, however, it is evident that the error is not serious since the points all lie close to a smooth curve of best fit.

Reproducible results could be obtained only if the solutions were thoroughly stirred from the moment of introduction of the lead fluoride. This prevented caking of the lead fluoride until the maximum amount had been dissolved, after which stage the onset of caking gave an indication that the solubility was decreasing owing to deposition of lead fluoaluminates.

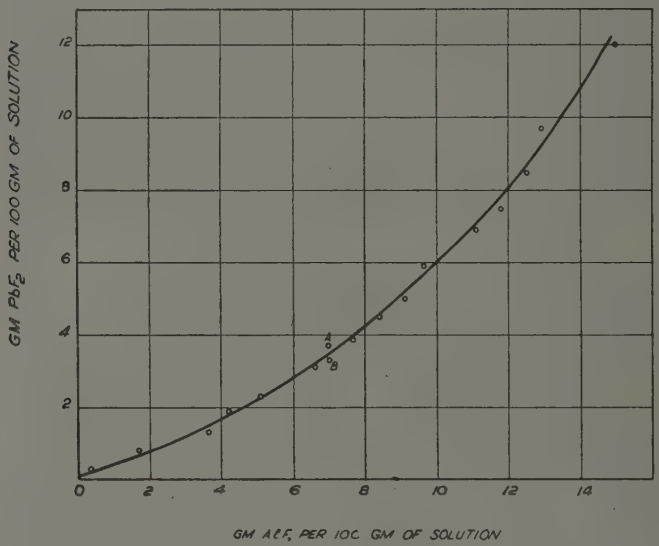

FIG. 1.—Solubility of lead fluoride in aluminium fluoride solutions at 25°C.

(ii) *Concentration of Aluminium Fluoride.*

Results are shown graphically in Fig. 1. The most concentrated solutions obtained were found to contain 12 per cent. of lead fluoride, compared with the low value of 0·064 per cent. for lead fluoride in water.

The concentration of lead fluoride increases more rapidly than that of aluminium fluoride; hence a precipitate is formed when concentrated solutions are diluted with water. Analysis of this material, after filtering and washing with small amounts of water and alcohol, showed the molar ratio AlF_3: PbF_2 to be 0·97: 1·00, from which it appears that the precipitate has the empirical formula $PbAlF_5$. If the precipitate is washed many times with water, however, the molar ratio AlF_3: PbF_2 in the dried solid is decreased considerably, indicating that the compound is incongruently soluble in water. For this reason, the compound could not be leached from melts of aluminium and lead fluorides having the composition of $PbAlF_5$, although the amounts of lead and aluminium in the resulting solutions were considerably greater than could be found in saturated solutions of the simple anhydrous fluorides.

(iii) *Acidity of Solutions.*

By adding hydrofluoric acid to aluminium fluoride solutions, the solubility of lead fluoride can be greatly decreased. The effect is illustrated in Fig. 2 for solutions which all contain the same concentration of aluminium fluoride (7·1 per cent.).

In the presence of relatively small amounts of acid, however, the maximum solubility is not significantly different from that for completely neutralized solutions. The values for points A (pH 2·75) and B (pH 1·87) in Fig. 2 both lie reasonably close to the best-fit solubility curve shown in Fig. 1, although at point B the solution contains 0·13 moles of hydrofluoric acid per mole of aluminium fluoride. There is little doubt that the solubility does decrease with decreasing pH even in such weakly acid solutions, but the errors inherent in the determination of the true maximum solubility tend to mask the effect.

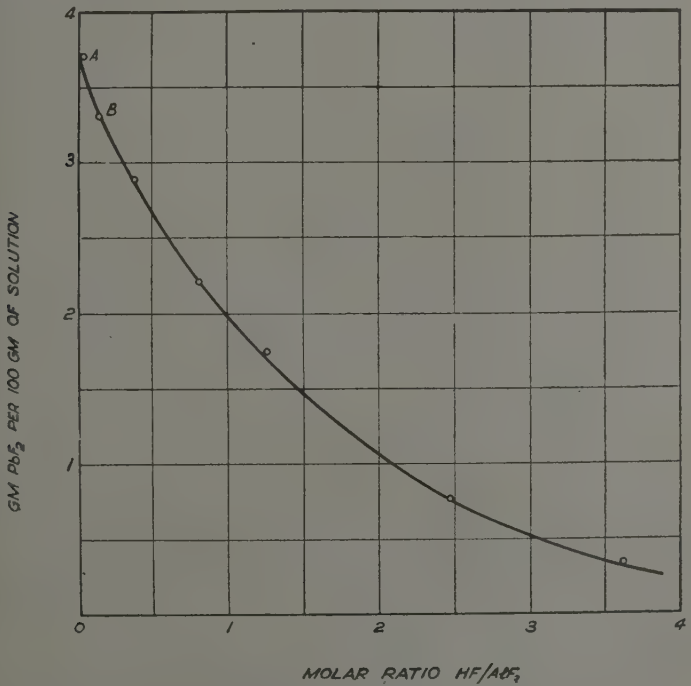

FIG. 2.- Effect of hydrofluoric acid on the solubility of lead fluoride in 7·1 per cent. aluminium fluoride solution.

By using a mixture containing two parts by weight of fluosilicic acid to fifteen parts of hydrofluoric acid, instead of pure hydrofluoric acid, the solubility of lead fluoride is increased by approximately 25 per cent. Such a mixture contains the two acids in the proportion commonly found in commercial grades of hydrofluoric acid.

Greatly *increased* solubilities occur when other acids, such as fluosilicic, perchloric, and acetic acids, are substituted for hydrofluoric acid in the above experiments.

(iv) *Temperature of Solutions.*

At high temperatures, the maximum solubility is reached more rapidly than at room temperature, and the aluminium fluoride solutions tend to deposit β–$AlF_3 . 3H_2O$ more readily. Solubility determinations are consequently difficult to perform satisfactorily. Comparative figures are given, however, in Table 1, for four points along the solubility curve, the values at 25°C. being taken from the curve in Fig. 1. These high-temperature determinations were done within the temperature range 90–98°C., and suffice to show that the temperature coefficient of solubility is relatively small.

TABLE 1.—EFFECT OF TEMPERATURE ON SOLUBILITY.

AlF_3, g./100 g. of Solution.	PbF_3, g./100 g. of Solution.	
	25°C.	90°C.
13·0	9·4	10·2
11·3	7·2	8·7
7·2	3·6	4·3
3·9	1·7	2·1

4. Discussion

Since the solubility product of lead fluoride is $7{\cdot}1 \times 10^{-8}$, it appears that the greatly enhanced solubility in aluminium fluoride solutions is due to a reduction in the concentration of lead or fluoride ions. This reduction may be brought about in three ways:—

(*a*) Formation of associated (non-ionized) molecules of lead fluoaluminate.

(*b*) Formation of complex ions of the type $PbF_4^=$.

(*c*) Formation of complex ions such as $AlF_6^{\equiv}$.

Of these suggestions, the first is improbable and no evidence has been adduced for the existence of PbF_4 anions. Lead fluoride is almost insoluble in hydrofluoric acid, and is immediately precipitated by the addition of lead nitrate to this acid. From solutions of lead fluoride in aluminium fluoride, lead sulphate is completely precipitated by the addition of sulphuric acid and the metal is rapidly deposited in spongy form on less noble metals placed in the solutions.

There is abundant evidence (1), however, that solutions of aluminium fluoride may contain complex ions of the type AlF^{++}, AlF_2^+, AlF_4^-, $AlF_5^=$ and $AlF_6^{\equiv}$. The existence of the complex cations is demonstrated by the fact that aluminium hydroxide is not precipitated at pH 4·1 when ammonia is added to these solutions. Instead, precipitation is delayed until the pH reaches a value of five or higher, and the precipitates apparently consist of aluminium oxyfluorides, or hydroxyfluorides, such as $AlF_2(OH)$. The complex anions are found in the various alkali and ammonium fluoaluminates which are precipitated on the addition of the appropriate compounds. The possibility

that "multiple core" ions, such as $(Al_3F_{14})^{5-}$, may be present has not been overlooked, but it is simpler to dismiss them from discussion, which may be done without prejudice to the suggestions put forward.

When lead fluoride is added to these solutions, the following reactions, involving the complex ions originally present, can be envisaged:—

$$F^- + AlF^{++} \rightleftharpoons AlF_2^+ \quad \ldots\ldots\ldots \quad (I)$$

$$F^- + AlF_2^+ \rightleftharpoons AlF_3 \quad \ldots\ldots\ldots \quad (II)$$

$$F^- + AlF_3 \rightleftharpoons AlF_4^- \quad \ldots\ldots\ldots \quad (III)$$

$$F^- + AlF_4^- \rightleftharpoons AlF_5^= \quad \ldots\ldots\ldots \quad (IV)$$

$$F^- + AlF_5^= \rightleftharpoons AlF_6^{\equiv} \quad \ldots\ldots\ldots \quad (V)$$

In this manner the fluoride ion concentration is held at a very low value and considerable concentrations of lead ions may exist in solution without the solubility product of lead fluoride being exceeded.

In solutions containing aluminium fluoride only, the various complex ions are present in definite equilibrium proportions, but with the introduction of lead and fluoride ions, these proportions are considerably changed. The delay in precipitation of lead fluoaluminates from such solutions may well be caused by a slow re-establishment of the equilibrium proportions of the complex ions. If it be assumed that one of the above reactions, such as reaction (I.), is predominant, high concentrations of lead ions may occur without the solubility product of lead fluoaluminates (such as $PbAlF_5$) being exceeded. With time, however, equilibrium between the complex ions will be re-established, with a consequent decrease in the concentration of AlF_2^+ ions and a proportionate increase in the concentration of ions such as $AlF_6^=$ At some stage in this process the concentration of $AlF_5^=$ ions will reach the level at which the solubility product of $PbAlF_5$ is exceeded and precipitation will commence. Support for this hypothesis is afforded by the observations of Brosset (1), who found that, with very dilute solutions of aluminium fluoride, as much as one hour may elapse before equilibrium is established between the various ions. Even if reaction (I.) is not predominant, this explanation still holds, provided only that reaction (IV.) is of minor importance and that $PbAlF_5$ is the least soluble of the various lead fluoaluminates which can be postulated.

Addition of acids to solutions of aluminium fluoride should increase the solubility of lead fluoride by depressing the fluorine ion concentration. Unequivocal results could not be obtained with nitric, fluosilicic, and perchloric acids, since lead fluoride is soluble in these acids in the absence of aluminium fluoride. A distinct increase in solubility was noted, however, when small amounts of fluosilicic acid were added to solutions already acidified with hydrofluoric acid (see above).

When hydrofluoric acid is present, the concentrations of all the complex ions, including $AlF_5^=$, are increased and less lead fluoride can be added before the concentration of $AlF_5^=$ becomes sufficient to cause

precipitation of $PbAlF_5$. The solubility of lead fluoride, therefore, shows a marked decrease with increasing concentration of hydrofluoric acid (Fig. 2). It is evident that the stage must eventually be reached where the supply of complex ions is inadequate to react completely with added fluorine. Even when the solution has the empirical composition of H_3AlF_6, however, the maximum amount of lead fluoride dissolved is appreciably greater than that dissolved by water or pure hydrofluoric acid.

In the light of the above explanation, it might be expected that other fluorides having very small solubilities would be much more soluble in aluminium fluoride solutions, but no increase in solubility was noted with the fluorides of barium, thorium, and magnesium (solubilities $0{\cdot}17^{10}$, $0{\cdot}020^{25}$, $0{\cdot}0076^{18}$ respectively; cf. PbF_2 $0{\cdot}064^{20}$). The critical factor is apparently the solubility of the corresponding fluoaluminate; if this be less soluble than the fluoride, as occurs with barium, no increase in the concentration of barium will be observed in the presence of aluminium fluoride solutions. Lead fluoaluminate, on the other hand, is more soluble than lead fluoride. The solubility of magnesium fluoride is so slight that it is difficult to check the solubility of the fluoaluminate, but the latter compound is slowly precipitated when magnesium sulphate is added to aluminium fluoride solution. Thorium fluoride is precipitated from solutions of aluminium fluoride on the addition of thorium nitrate, but it is doubtful whether a fluoaluminate of thorium exists at all.

When small quantities of thorium nitrate are added to a clear solution of lead fluoride in aluminium fluoride, thorium fluoride is precipitated. From calculations based on the solubilities given above, however, lead fluoride might be expected to precipitate just as readily, since the concentration of lead ions is very much greater than that of thorium ions. This behaviour of thorium fluoride may be explained on the assumption that the quoted solubility is too great, a possibility which is further indicated by the following facts. When lead nitrate is added to an excess of hydrofluoric acid, a heavy precipitate of lead fluoride is obtained, but with added nitric acid the precipitate is quickly dissolved. This effect is undoubtedly due to depression of the fluorine ion concentration below the value required to cause precipitation of lead fluoride, yet when thorium nitrate is added an immediate precipitate of thorium fluoride is formed. It is, of course, conceivable that sufficient PbF^+ ions are present to reduce the concentration of lead and fluorine ions in these solutions, but it is difficult to assess the effect of this upon the solubility of lead fluoride, since enough is not known about the value of the solubility product $[PbF^+]\,[F^-]$.

5. Applications

From the experimental results, it is evident that lead is unsuitable for use in the presence of aluminium fluoride solutions. Although the contamination of these solutions is very much reduced by the addition of hydrofluoric acid, the quantity of lead fluoride dissolved is still sufficient to give 0·2—0·3 per cent PbF_2 in the recovered aluminium fluoride, while the accompanying corrosion of the lead vessels is well beyond the limits which can be tolerated. The phenomenon has even been observed in the preparation of cryolite by

the neutralization of trisodium aluminate solutions with hydrofluoric acid in lead vessels, the resulting cryolite containing up to 0·4 per cent. lead fluoride.

Attempts have been made to overcome this corrosion by developing, on the lead surfaces, protective films of less soluble lead salts, such as the sulphate and chromate, but in no instance could sufficiently coherent and impervious films be obtained.

It is probable that this severe corrosion of lead vessels is not confined to solutions of aluminium fluoride, but may occur in any solution containing a variety of complex metallo-fluoride ions. The essential requirement appears to be that reactions of the type, $AlF_4^- + F^- \rightleftharpoons AlF_5^=$ and $AlF^{++} + F^- \rightleftharpoons AlF_2^+$, should be possible and many fluorides of the metals of higher valency, such as iron, chromium, vanadium, zirconium, and tantalum, comply with this condition. Support for this belief has been afforded by the observation (4) that, when zirconium phosphate is dissolved in hydrofluoric acid, using a lead vessel, considerable quantities of lead are found in solution.

In many operations involving the use of hydrofluoric acid, it is thus advisable to use vessels constructed of metals other than lead. It is possible, of course, to use synthetic resins, wood, graphite, &c., but there are occasions where a metal is more convenient and suitable. In such instances, the choice lies between metals which acquire an insoluble protecting fluoride film and those which are highly cathodic in the presence of acids. Dow metal (an alloy of magnesium and aluminium) belongs to the first group, and experiments described above have shown that the magnesium fluoride film is practically insoluble in aluminium fluoride solutions. Should the film be damaged, however, rapid corrosion of the metal may occur, and the subsequent re-establishment of a continuous and impervious film may be impracticable. To the second group belong metals such as copper, monel, and silver, which show little or no reaction with aqueous hydrofluoric acid, although the respective fluorides are quite soluble. Of these, silver is the most highly cathodic, but monel is probably the most suitable for everyday use, having the advantage over copper that joints in monel apparatus may be welded with monel scrap. No corrosion of monel ware has been observed in any of the experiments described in the course of this paper.

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Theory of the Bourdon Tube

*By Elizabeth H. Mann, B.A.**

Summary.

A paper by H. Lorenz on the theory of the Bourdon tube pressure gauge has been reviewed and an alternative approach developed. This is only a first order approximation, and gives best results for flat thin-walled tubes.

Symbols

a	..	Length of major semi-axis of tube cross-section (parallel with ZZ axis)
b	..	Length of minor semi-axis of tube cross-section
$2h$	..	Wall thickness (Lorenz uses h)
r_0, R	..	Radius of curvature of the tube (measured at major axis of symmetry)
r	..	Radius of curvature at any point on tube cross-section about ZZ axis
χ	..	Angle subtended at ZZ axis by arc of tube
p	..	Pressure difference in tube
σ'	..	Tangential or ring stress
σ''	..	Transverse or meridian stress
ZZ	..	Axis of curvature of the tube
Φ	..	Angle formed by the ZZ axis and the tangent at any point on the meridian line of the tube cross-section
θ	..	Polar angle of the ellipse
$\overline{M'}$	..	Bending moment along a meridional boundary of tube wall
$\overline{M''}$	..	Bending moment along a tangential boundary of tube wall
τ	..	Normal shear along a tangential boundary of tube wall
τ'	..	Normal shear along a meridional boundary of tube wall
ρ'	..	Radius of curvature of a principal section normal to meridian curve
ρ''	..	Radius of curvature of meridian curve of cross-section
κ	..	Change in principal curvature $\frac{\cos \Phi}{r}$
κ'	..	Change in principal curvature ρ''

Suffixes 1 and 2 are used to denote initial and final states respectively.

* An officer of the Division of Aeronautics.

1. Introduction

This investigation commenced as a review of an article by H. Lorenz on the theory of the Bourdon tube pressure gauge[1]. This led to the study of other papers on the same subject and finally to a fresh attempt to solve the problem.

2. Discussion

The article by Lorenz[1] will be considered first. His problem is to determine the stresses and deflection of a curved tube of elliptical cross-section under an internal pressure p. The tube is curved so that its axis forms an arc of a circle subtending an angle χ at the centre. The major axis of the ellipse generates a cylinder about the ZZ axis (see Fig. 1).

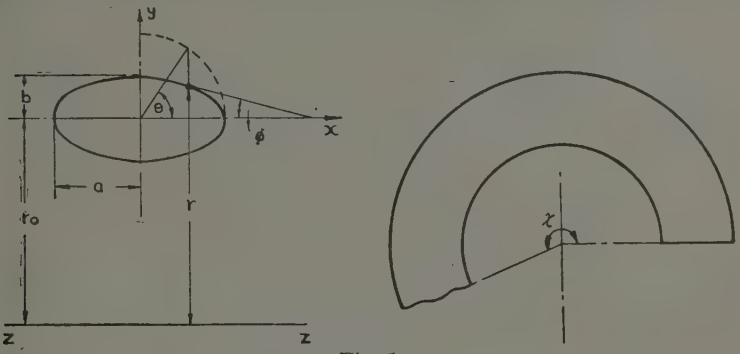

Fig. 1

The tube is closed by soldered-on end pieces. When stressed these might well cause some outward bending of the walls of the tube, but experience shows that such bending moments die away rapidly at a short distance from the end. Thus there is justification for the omission of these terms and the assumption that the stress system does not vary with χ. However, Lorenz goes further than this and assumes axial symmetry, which enables him to use equations of equilibrium previously derived for a closed ring. This involves a contradiction, since the method is to be used to calculate the change in angle χ, implying a tangential displacement which is impossible under axial symmetry.

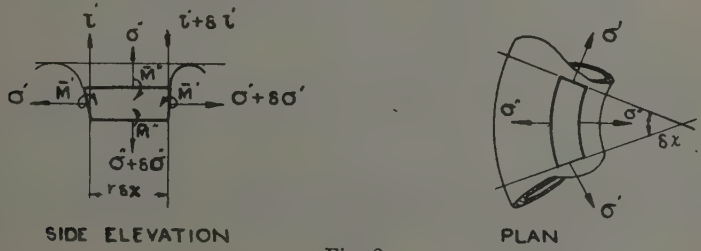

Fig. 2

Moreover, the simplification made in neglecting the bending due to end effects is no reason for omitting $\overline{M'}$ altogether, as Lorenz has done (see Fig. 2). His argument is this: from consideration of the equilibrium of

an element of the tube bounded by lines of constant r and χ, and neglecting the quantities τ' and $\overline{M'}$, three equations are derived connecting the tensions σ', σ'', the shear τ, and bending moment M'' with the pressure p.

These are

$$\sigma'' = \frac{p}{h}\,\frac{r^2 - r_0^2}{2r\cos\Phi} + \tau\tan\Phi$$

$$\sigma' = \frac{p\rho'}{h}\left(1 - \frac{r^2 - r_0^2}{2r\rho''\cos\Phi}\right) - \frac{1}{\rho''}\,\frac{\partial}{\partial\Phi}\left(\frac{\tau r}{\cos\Phi}\right)$$

$$\frac{\partial\overline{M}''}{\partial s} = h\tau r\chi$$

where $ds = \rho''d\Phi$ is the element of arc of the meridian curve, and ρ', ρ'' are radii of curvature.

To solve these τr is replaced by $A\cos\Phi\sin\Phi$ and the constant A found from the condition that the strain energy is to be a minimum.

The resultant bending moment acting on the tube is, according to Lorenz, given by

$$M' = \int (r - r_0)\ \sigma'\ hds.$$

The strain energy L may then be expressed as a function of p, and the relative rotation $\triangle\chi$ of the ends of the tube found from the relation

$$\triangle\chi = \frac{\partial L}{\partial\overline{M'}} = \frac{\partial L}{\partial p}\,\frac{\partial p}{\partial\overline{M'}}.$$

Taking the points in order, the more exact equations

$$\frac{\partial}{\partial r}\,(\sigma''\ r\cos\Phi) - \frac{pr}{h} - \frac{\partial(\tau r\sin\Phi)}{\partial r} + \frac{\partial\tau'}{\partial\chi} = 0$$

$$\sigma' = \frac{p\rho'}{h} - \frac{1}{\rho''\cos\Phi}\,\frac{\partial(\tau r)}{\partial\Phi} - \frac{\sigma''\rho'}{\rho''} - \frac{1}{\cos\Phi}\,\frac{\partial\tau'}{\partial\chi}$$

$$\frac{\partial(\sigma'\rho'')}{\partial\chi} = \rho''\tau'\cos\Phi$$

$$\frac{\partial(\overline{M}''r)}{\partial s} = h\tau r - \overline{M'}\sin\Phi$$

$$\frac{\partial\overline{M'}}{\partial\chi} = h\tau' r$$

reduce to those given by Lorenz on omitting τ' and integrating the first with respect to r. The last gives $\overline{M'}$ constant with respect to χ but not necessarily zero. $\overline{M}''$ is the bending moment per unit length, so that

$$M'' = \overline{M}''r\chi$$

and Lorenz's third equation follows if $\overline{M'}$ is zero. Whether or not it can be zero will be discussed later.

The substitution of $A \cos \Phi \sin \Phi$ for τ is suggested by the assumption that the tube retains its doubly symmetrical cross-section, so that τ vanishes at $\Phi = \frac{n\pi}{2}$ $(n = 1, 2 \ldots)$. This sort of simplification is justified by common practice, and the assumption itself is consistent with his general assumption of infinitesimal strain.

The next point, however, is more troublesome. If M' represents the resultant bending moment of the stresses about a point on the axis of the tube, this must be equal to the moment of the external forces about the same point. The latter is due to the pressure acting on the walls and closed end of the tube to one side of the point about which the moment is to be found. This moment is readily shown to be zero not only for a tube of elliptic or circular cross-section but for any tube the cross-section of which has an axis of symmetry parallel to the ZZ axis (App. I.). If then M' is to represent the resultant moment it must be identically zero, and $\frac{\partial p}{\partial M'}$ is meaningless.

On the other hand the resultant moment is in fact equal to

$$\int \left((r - r_0)\ \sigma' h - \overline{M'} \cos \Phi \right) ds$$

so that his M' may be non-zero if $\overline{M'}$ does not vanish. This is one of the main contradictions in the work, that $\overline{M'}$ is neglected in the governing equations, while equilibrium considerations demand that it be sufficiently large to compensate the moment about the centroid due to the σ'.

Finally it is hard to justify the step

$$\triangle \chi = \frac{\partial L}{\partial M'}.$$

for the rotation at the end; for the governing equations do not apply at the ends, M' is not the resultant couple acting on the tube, and if it were it would have to be zero at the free end. The latter in Lorenz's equations would make not only M' but p and all the stresses zero everywhere.

These considerations made the solution appear of doubtful value, and it was felt that some alternative should be found.

The articles by Case[2] and Beskin[3] on the bending of curved tubes were not applicable since in this case the resultant bending moment about a point on the axis of the tube is zero. (App. I.) Both replace a bending moment by a statically equivalent system of varying pressure within the tube, and at first it was thought that the reverse method might yield results.

Qualitative accounts of the Bourdon tube had been given by Hill[6], Worthington[7], and Greenhill[8] by the end of last century. They discussed some of the difficulties of the problem and described the most suitable dimensions for a tube of high sensitivity.

Lord Rayleigh[5] mentions the Bourdon tube as an example of Gauss's Theorem, that if extension is neglected the state of bending of a thin shell will be such that the product of the principal radii of curvature remains

constant. He points out, however, that, for an elliptical cross-section, pure bending cannot occur, and suggests replacing the two halves of the ellipse by symmetrical curves meeting at a finite angle.

Experimental results supporting the view that the deflection is largely due to inextensional bending are given by Wuest[9]. He calculates the path followed by the free end of the tube on the assumption that $(r\chi)$ has the same value before and after strain. He also deduces the locus of the instantaneous centre of curvature of the path, and verifies this experimentally. Reference is made to a paper by Strohmeyer[10], who discusses the Bourdon tube at length, describing the shearing effect between adjacent longitudinal strips. He suggests that the ideal cross-section for the gauge would be lip-shaped, not elliptic, to reduce this effect.

Sunatani[11] uses the theory of a straight tube under internal pressure by neglecting the curvature of short elements of the tube. In effect, he neglects longitudinal bending, which he justifies by showing that the resultant bending moment due to the pressure is zero (as in App. I.). Actually this moment is zero only about points on the axis of the tube, not in the walls. However, the effect of longitudinal bending is usually small compared with bending of the section, and his work is supported by experimental results. The deflection of the free end is calculated, shown to be largely dependent on the terms due to inextensional bending, and on the basis of these an improved mechanism devised to give a linear scale reading.

The problem of a tube of circular cross-section is discussed by Dean[4]. His tube forms a closed ring so is not really applicable to the Bourdon tube, but several closely analagous difficulties arise. He is led to the conclusion that the theory based on small displacements is not satisfactory, owing to the occurrence of large and approximately inextensional displacements which tend to make the circular cross-section oval.

The same difficulty arises with the Bourdon tube from the vanishing of the moment due to the pressure. The hypothesis that the displacements are small, implying that an element of the shell is in approximately the same position before and after strain, must be abandoned, and the difference between initial and final co-ordinates taken into account.

Under high pressure the elliptic cross-section will distort, tending to a circular shape, and causing a displacement away from the ZZ axis if $r > r_0$ and towards it if $r < r_0$. In consequence, different longitudinal strips have different centres of curvature, and if the angle χ remained the same the outer side of the tube would be in tension and the inner in compression. Equilibrium is attained by a change of both radius and angle causing the tube to straighten.

Another straightening effect is due to the extension of the tube caused by the pressure on the ends. Tangential extension of each element causes an increase in the radius of curvature and hence a small deflection, of the order of strain.

If the cross-section is circular it will not distort, but the increase in the radius will have a straightening effect on the tube. This will be of the same order of magnitude as the effect of longitudinal strain so both must be considered in the circular case.

If, however, the cross-section is fairly flat, with minor axis in the plane of bending, and the walls of the tube are thin, it is to be expected that the main effect is due to distortion towards the circular form. This problem seems to demand a treatment based on pure bending of a thin shell.

3. Approximate Solution

In this approach the difference between initial and final co-ordinates is no longer negligible. The suffix 1 indicates the initial state and suffix 2 the final. Lorenz's quantity r_0 is replaced by R_1 and R_2 respectively.

Pure bending only is considered, the effect of extension being neglected. Thus all lengths in the middle surface are supposed to remain the same after strain as they were before, although the form of the surface may alter considerably. For example, if the axis of the tube initially subtends an angle χ_1 at the centre of a circle of radius R_1, and after strain subtends an angle χ_2, then the new radius R_2 is given by

$$R_1\chi_1 = R_2\chi_2$$

In this way the final state may be expressed as a function of the initial state and only one other variable, that is, if the initial form of the tube and the final value of one dimension are known, the final state is determined. The variable chosen below is b_2, the final value of the minor semi-axis of the ellipse. The major axis can be expressed in terms of this from the condition that the length of the perimeter remain the same. Moreover, although it is not possible in the elliptic tube[5] for pure bending of the cross section to lead to pure bending longitudinally, yet for a fairly flat tube the extreme outer and inner parts of the shell will have most effect, and may be used to express χ_2 as a function of b_2. For, if no extension occurs

$$(R_1 + b_1)\chi_1 = (R_2 + b_2)\chi_2$$
$$(R_1 - b_1)\chi_1 = (R_2 - b_2)\chi_2$$

Therefore

$$\frac{b_1}{b_2} = \frac{\chi_2}{\chi_1} = \frac{R_1}{R_2}$$

Having expressed the dimensions of the strained tube as functions of b_2, it only remains to find b_2 as a function of the pressure in the tube and the elastic constants of the material. This is done by using the theorem that the total energy of the system must be stationary for equilibrium, requiring that the increase of strain energy in a small displacement from equilibrium is equal to the work done by the internal pressure. Solving this equation gives b_2 and hence the other unknowns.

This method has been applied to the elliptic tube and also to one of lip-shaped cross section as suggested by Strohmeyer[10]. Both involved elliptic integrals and it was found convenient to approximate to the solution by power series. It was not considered worth while to take many terms of the series since the solution is already incapable of accuracy due to neglecting extension and assuming the form of the final shape.

The elliptic case alone will be given in detail. The form taken for the lip-shaped cross section was given by

$$y = b \cos^2 \frac{\pi x}{2a} .$$

The length of the perimeter is then

$$s = 4 \int_0^a \sqrt{1 + \frac{\pi^2 b^2}{4a^2} \sin^2 \frac{\pi x}{a}}\, dx$$

$$= 4b \sqrt{1 + \frac{4}{\pi^2}} \int_0^{\frac{\pi}{2}} \sqrt{1 - \frac{1}{1 + \frac{4a^2}{\pi^2 b^2}} \sin^2 x}\, dx$$

This is expanded as a series in powers of $\frac{1}{1 + \frac{4a^2}{\pi^2 b^2}}$. The procedure otherwise is similar to that in the elliptic case.

An ellipse of semi-axes a_1, b_1 is supposed to bend without extension to form an adjacent ellipse of semi-axes a_2, b_2. A point on the first ellipse moves to a neighbouring point on the second at the same distance along the curve from an extreme point, that is

$$s_1 = \int_0^{\theta_1} \sqrt{a_1^2 - (a_1^2 - b_1^2) \cos^2 \theta}\, d\theta$$

$$= \int_0^{\theta_2} \sqrt{a_2^2 - (a_2^2 - b_2^2) \cos^2 \theta}\, d\theta$$

$$= s_2 \qquad \text{(1)}$$

For $\theta_1 = \theta_2 = \frac{\pi}{2}$ this relation may be used to express a_2 in terms of a_1, b_1, and b_2 by an equation of the form

$$a_2 - a_1 \approx - C_1 (b_2 - b_1) \qquad \text{(2)}$$

where C_1 is, to a first approximation, a function of a_1, b_1 only, and is of the order of (b/a).

The above equation was obtained by expansion of the elliptic integrals in series of powers of b^2/a^2. For other values of θ_1 and θ_2 this is not so readily done, and the following approximation was made.

It was found graphically that $\theta_1 - \theta_2$, which is of course zero at $\theta = 0$, $\frac{\pi}{2}$, increases smoothly to a maximum at $\theta = \frac{\pi}{2}$, remaining always small for adjacent ellipses. Fitting a function to this curve, the form

$$(\theta_2 - \theta_1) = - \eta \sin \theta \cos \theta \qquad \text{(3)}$$

was assumed, where η may be determined from the value of $\theta_2 - \theta_1$ at $\theta = \frac{\pi}{4}$, namely

$$\theta_2 - \theta_1 \approx \left\{ \int_0^{\frac{\pi}{4}} \sqrt{a_1^2 - (a_1^2 - b_1^2)\cos^2\theta}\, d\theta - \int_0^{\frac{\pi}{4}} \sqrt{a_2^2 - (a_2^2 - b_2^2)\cos^2\theta}\, d\theta \right\} \frac{\sqrt{2}}{\sqrt{a_1^2 + b_1^2}}$$

$$\approx \left\{ \int_{\frac{\pi}{4}}^{\frac{\pi}{2}} \sqrt{a_2^2 - (a_2^2 - b_2^2\cos^2\theta}\, d\theta - \int_{\frac{\pi}{4}}^{\frac{\pi}{2}} \sqrt{a_1^2 - (a_1^2 - b_1^2)\cos^2\theta}\, d\theta \right\} \frac{\sqrt{2}}{\sqrt{a_1^2 + b_1^2}}$$

for convenience in evaluating the integrals (App. II.). This finally gives

$$(\theta_2 - \theta_1) \approx -\frac{2\sqrt{2}}{\sqrt{a^2 + b^2}} C_2 \sin\theta \cos\theta (b_2 - b_1) \quad \ldots\ldots (4)$$

where C_2 is another function of a_1, b_1.

Equations (2) and (4) are needed to ensure that the same point is considered in its initial and final positions. This is necessary in valuating the strain energy, which is given by

$$U = \iint \tfrac{1}{2} D \left[(\kappa + \kappa')^2 - 2(1 - \sigma)\kappa\kappa' \right] dS \quad \ldots\ldots (5)$$

integrated over the middle surface of the shell (see ref. 12, p. 504). Here

$$D = \frac{2}{3} \frac{Eh^3}{1 - \sigma^2}$$

where $2h$ is the thickness of the shell, E is Young's modulus and σ Poisson's ratio, and κ, κ' are increments in the principal curvatures.

In a small displacement from equilibrium the work done by the internal pressure is approximately p (increase in enclosed volume) $= p\delta(\pi R_2 \chi_2 a_2 b_2)$ and must equal the increase in the strain energy

$$p\delta(\pi R_2 \chi_2 a_2 b_2) = \delta U \quad \ldots\ldots (6)$$

giving b_2 as a function of p, and hence the other unknowns.

In expressing the strain energy as a function of b_2 a number of series approximations are needed. The lines of curvature are the lines $\chi =$ constant and $\theta =$ constant, so the principal curvatures are respectively

$$\frac{\cos \Phi}{r}$$

where $\tan \Phi = -\frac{dy}{dx} = \frac{b}{a} \cot \theta$, and

$$\frac{b}{a^2(1 - e^2 \cos^2 \theta)^{\frac{3}{2}}}$$

where $e^2 = \frac{a^2 - b^2}{a^2}$. The quantities κ and κ' are then the changes in these quantities on going from the point at θ_1 on the first ellipse to θ_2 on the second,

$$\kappa = \frac{\cos \Phi_2}{r_2} - \frac{\cos \Phi_1}{r_1}$$

$$\kappa' = \frac{b_2}{a_2^2 (1 - e_2^2 \cos^2 \theta_2)^{\frac{3}{2}}} - \frac{b_1}{a_1^2 (1 - e_1^2 \cos^2 \theta_1)^{\frac{3}{2}}}$$

Taking the first terms of series expansions in powers of $\frac{a_2 - a_1}{a_1}, \frac{b_2 - b_1}{b_1}$ and $\frac{\theta_2 - \theta_1}{\theta_1}$, and using (2) and (3) these become

$$\kappa \approx \eta \left(- \frac{R_1 \sin \theta_1 \cos^2 \theta_1}{r_1^2 a^{\frac{1}{2}}} + \frac{e_1^2 \sin^3 \theta_1 \cos^2 \theta_1}{r_1 a^{\frac{5}{2}}} \right)$$

$$+ (b_2 - b_1) \left(- \frac{\sin \theta_1}{b_1 r_1 a^{\frac{1}{2}}} - \frac{b_1 \sin \theta_1 \cos^2 \theta_1}{a_1^2 r_1 a^{\frac{3}{2}}} \left(1 + \frac{b_1 C_1}{a_1} \right) \right)$$

$$\kappa' \approx \eta \cdot \frac{3 b_1 e_1^2 \sin^2 \theta_1 \cos^2 \theta_1}{a_1^2 a^{\frac{5}{2}}} + \frac{(b_2 - b_1)}{a_1^2 a^{\frac{3}{2}}} \left(1 + \frac{2 b_1 C_1}{a_1} \right.$$

$$\left. - \frac{3 b_1^2}{a_1^2 a} (1 + \frac{b_1 C_1}{a_1}) \cos^2 \theta_1 \right)$$

where $a = 1 - e_1^2 \cos^2 \theta_1$. These are to be substituted in (5) using (4) to give an expression of the form

$$U \approx (b_2 - b_1)^2 F$$

which is obtained after tedious expansion in series of elliptic integrals (see App. II.).

Then using (6)

$$\begin{aligned}\delta(p\pi R_2\chi_2 a_2 b_2) &= p\pi R_1\chi_1(b_2\delta a_2 + a_2\delta b_2)\\ &\approx p\pi R_1\chi_1(a_1 - C_1 b_1)\delta b_2\\ &\approx 2(b_2 - b_1)F\delta b_2\end{aligned}$$

so that

$$b_2 - b_1 \approx \frac{p\pi R_1\chi_1(a_1 - C_1 b_1)}{2F}$$

This is the method used, but for various reasons it is not satisfactory. Comparison with experimental results on eight gauges at the Division of Metrology, C.S.I.R., showed that the theoretical treatment gave deflections considerably too small, varying from 2/3 to 1/8 of the experimental. This means that the tube of this theory is stiffer than the actual one, whereas Sunatani's[11] method made the tube too flexible, giving from twice to eleven times the deflection.

Several causes may contribute to this lack of agreement, the main one probably being the initial assumption that the ellipse distorts into another ellipse. In passing to the corresponding point on a neighbouring ellipse the change of curvature κ' is small, and comparable with the change on going to a neighbouring point on the same ellipse. Thus if the final form in fact differs only slightly from an ellipse it may make a considerable difference to the result.

This does not mean that results deduced for an elliptic cross section can not be applied to a tube of a slightly different form; but in estimating the behaviour for the case of the ellipse the final form should really be deduced, not assumed.

The assumption that the deflection of the end of the tube is largely due to inextensional bending was supported to some extent by the experimental results mentioned above. Values of $\frac{b_2 - b_1}{b_1}$ and $\frac{\chi_1 - \chi_2}{\chi_2}$ calculated from them are given below for comparison. They show that bending theory may well be used to estimate the order of strains involved.

$\frac{b_2 - b_1}{b_1}$ ..	·023	·036	·026	·035	·023	·032	·024	·020
$\frac{\chi_1 - \chi_2}{\chi_2}$ ..	·031	·026	·020	·028	·023	·025	·025	·026

4. Conclusions

The Bourdon tube straightens under pressure due to the distortion of its cross section towards a circular shade. For thin-walled tubes the effect is due chiefly to inextensional bending of the shell, so that in certain cases the direct stresses may be neglected.

A simplified theory of this kind has been devised here by assuming the form but not the amount of the distortion. On comparing the calculated deflections with experiment they were found to be too small, ranging from 2/3 to 1/8 of the experimental values. It is possible that the results could be improved by retaining second order terms in the series used, but an exact solution is not obtainable by this method.

For real accuracy the form of the strained tube could not be assumed, but would have to be deduced from thin shell theory. A possible approach would be to neglect the direct stresses and strains in the equations of equilibrium and attempt to solve the problem in terms of the two principal curvatures and bending moments.

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Appendix I

Proof that the bending moment about a point on the axis of a closed curved tube due to internal pressure on its walls is zero for all tubes having an axis of symmetry perpendicular to the plane of bending.

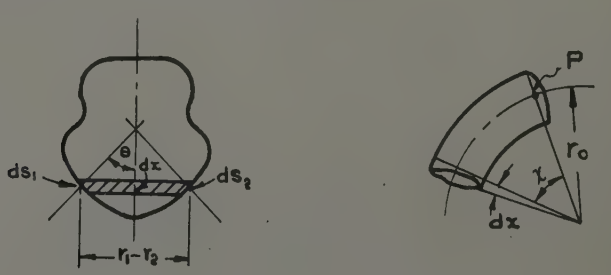

Fig. 3.

Consider the moment about P due to the pressure on an element of the tube which subtends the angle $\delta\chi$ at O, a point on the ZZ axis. The same pressure p acts normal to the surface elements ds_1 and ds_2 which are of the same length in the plane of the cross section but differ by $(r_1 - r_2)\delta\chi$ along the tube. The resultant outward thrust due to pressure is

$$p\,ds \sin\theta(r_1 - r_2)d\chi = p\,.\,dA\,.\,d\chi$$

where dA is the shaded element of area. For the whole cross section it is $Ad\chi$, with moment about P given by

$$dM = pr_0 \sin\chi A d\chi$$

Thus the total moment from elements from $\chi = 0$ to $\chi = \chi_1$ say is

$$M = pr_0 A(1 - \cos\chi_1)$$

in a clockwise sense about P.

The moment due to the pressure on the closed end is

$$\int (r - r_0 \cos\chi_1)p dA'$$

where dA' is now an element of area parallel to the axis and distant r from it. For a symmetrical cross section this reduces to the moment

$$M' = pr_0 A(1 - \cos\chi_1)$$

in the anti-clockwise sense.

The total moment about P is then

$$M - M' = 0$$

as required.

Appendix II

In determining η as a function of $(b_2 - b_1)$ it was necessary to express the elliptic integral

$$\int_{\frac{\pi}{4}}^{\frac{\pi}{2}} \sqrt{a^2 \sin^2\theta + b^2 \cos^2\theta}\; d\theta$$

as a function of a, b. This may be done by expanding as a series in powers of $\frac{b^2}{a^2 - b^2}$, converging uniformly if b/a is small.

$$\int_{\frac{\pi}{4}}^{\frac{\pi}{2}} \sqrt{a^2 \sin^2\theta + b^2\cos^2\theta}\, d\theta = \sqrt{a^2-b^2}\int_{\frac{\pi}{4}}^{\frac{\pi}{2}} \sqrt{1+\frac{b^2}{a^2-b^2}\operatorname{cosec}^2\theta}\,\sin\theta\, d\theta$$

$$\approx \sqrt{a^2-b^2}\int_{\frac{\pi}{4}}^{\frac{\pi}{2}} \left(\sin\theta + \tfrac{1}{2}\frac{b^2}{a^2-b^2}\operatorname{cosec}\theta - \tfrac{1}{8}\frac{b^4}{(a^2-b^2)^2}\operatorname{cosec}^3\theta\right)d\theta$$

$$= \sqrt{a^2-b^2}\left[\frac{1}{\sqrt{2}} - \tfrac{1}{2}\frac{b^2}{a^2-b^2}\log_e\tan\frac{\pi}{8} + \frac{1}{16}\frac{b^4}{(a^2-b^2)^2}\left(-\sqrt{2}+\log_e\tan\frac{\pi}{8}\right)\right]$$

The other elliptic integrals which occur in evaluating the strain energy are all complete integrals, that is integrated in the range 0, $\frac{\pi}{2}$. They were expanded in powers of b^2/a^2, using the series given by Jahnke and Emde (ref. 13, p. 73). In their notation the integrals

$$K = \int_0^{\frac{\pi}{2}} \frac{d\theta}{\sqrt{1-e^2\sin^2\theta}} = \int_0^{\frac{\pi}{2}} \frac{d\theta}{\sqrt{1-e^2\cos^2\theta}}$$

and

$$C = \int_0^{\frac{\pi}{2}} \frac{\sin^2\theta\cos^2\theta\, d\theta}{(1-e^2\sin^2\theta)^{3/2}} = \int_0^{\frac{\pi}{2}} \frac{\sin^2\theta\cos^2\theta d\theta}{(1-e^2\cos^2\theta)^{3/2}}$$

are given as series in powers of $k'^2 = \frac{b^2}{a^2}$, the coefficients involving $\nu = \log_e \frac{4a}{b}$. Since these series converge uniformly for small values of b/a it is possible to obtain other series expansions by differentiating term by term and forming linear combinations, using the relation

$$e^2 = 1 - \frac{b^2}{a^2}$$

For instance

$$\int_0^{\frac{\pi}{2}} \frac{\sin^2\theta\cos^4\theta\, d\theta}{(1-e^2\cos^2\theta)^{5/2}} = \frac{2}{3}\frac{dC}{de^2}$$

$$= -\frac{2}{3}\frac{d}{d(b^2/a^2)}\left(\nu - 2 + \frac{9}{4}(\nu - \frac{5}{3})\frac{b^2}{a^2} + \dots\right)$$

$$= \frac{a^2}{3b^2} - \frac{3\nu}{2} + \frac{13}{4} + \dots$$

The integral

$$\int_0^{\frac{\pi}{2}} \frac{d\theta}{(1 - e^2 \cos^2 \theta)^{5/2}}$$

is obtained by differentiation and addition

$$\int_0^{\frac{\pi}{2}} \frac{d\theta}{(1 - e^2 \cos^2 \theta)^{5/2}} = K + 2e^2 \frac{dK}{de^2} + \frac{2e^2}{3} \frac{d}{de^2}\left[K + 2e^2 \frac{dK}{de^2}\right]$$

$$= \frac{2}{3} \frac{a^4}{b^4} + \frac{1}{2} \frac{a^2}{b^2} + \frac{3\nu}{8} - \frac{7}{32}$$

From this the integrals $\int_0^{\frac{\pi}{2}} \frac{\cos^2 \theta \, d\theta}{(1 - e^2 \cos^2 \theta)^{7/2}}$

and $\int_0^{\frac{\pi}{2}} \frac{\cos^4 \theta \, d\theta}{(1 - e^2 \cos^2 \theta)^{9/2}}$

are readily obtained by differentiation as above.

Integrals containing higher powers of sin θ in the numerator may be obtained by using the formula :

$$\frac{1}{(1 - e^2 \cos^2 \theta)^n} = \frac{1 - e^2}{(1 - e^2 \cos^2 \theta)^{n+1}} + \frac{e^2 \sin^2 \theta}{(1 - e^2 \cos^2 \theta)^{n+1}}$$

for instance :

$$\int_0^{\frac{\pi}{2}} \frac{\sin^4 \theta \, d\theta}{(1 - e^2 \cos^2 \theta)^{5/2}} = \frac{1 - e^2}{e^2} \int_0^{\frac{\pi}{2}} \frac{\sin^2 \theta \, d\theta}{(1 - e^2 \cos^2 \theta)^{5/2}}$$

$$+ \frac{1}{e^2} \int_0^{\frac{\pi}{2}} \frac{\sin^2 \theta \, d\theta}{(1 - e^2 \cos^2 \theta)^{3/2}}$$

and the integrals on the right are similarly expressed in terms of

$$\int_0^{\frac{\pi}{2}} \frac{d\theta}{(1 - e^2 \cos^2 \theta)^{5/2}}, \int_0^{\frac{\pi}{2}} \frac{d\theta}{(1 - e^2 \cos^2 \theta)^{3/2}} \text{ and } \int_0^{\frac{\pi}{2}} \frac{d\theta}{(1 - e^2 \cos^2 \theta)^{\frac{1}{2}}}.$$

In this manner all the elliptic integrals required are represented approximately by the first few terms of series in powers of b^2/a^2.

A Report on Commercial Tuna Trolling Tests in South-Eastern Australia.

*By D. L. Serventy, B.Sc., Ph.D.**

Summary.

A commercial tuna trolling test in the waters of Tasmania and New South Wales in 1941 was sponsored by the C.S.I.R., but the results proved disappointing.

The fishing results are analysed and among the conclusions drawn is the fact that southern bluefin tuna fluctuate strongly in abundance and other characteristics in south-eastern Australia.

1. Introduction.

The Division of Fisheries investigation vessel, M.V. *Warreen,* conducted surveys in south-eastern Australia for tuna and other pelagic fish from the time of its commissioning in May, 1938, to June, 1942, when its operations ceased owing to the war. Attention was directed to three principal methods of fishing for tuna: (1) by trolling; (2) pole-fishing with live bait; (3) purse-seining.

During the period, only a limited amount of tuna had been caught for commercial purposes in Australia, and that almost entirely by trolling. The desirability of proving the possibilities of the troll fishery by a comprehensive commercial test, in association with the C.S.I.R., early became apparent and was made more urgent by war-time needs for processed fish.

The tuna trolling tests were eventually carried out in 1941, in Tasmania and New South Wales. They developed out of a recommendation by Mr. S. Fowler to Dr. H. Thompson (Chief of the Division of Fisheries) that, since he believed the existing research vessel, M.V. *Warreen,* could not give detailed attention to several fisheries over a wide area at the same time, two smaller boats be built for intensive research and demonstration of fishing methods in south-eastern Australia. At the time of this recommendation, it was proposed to build a new research vessel for explorations in Western Australia, and Mr. Fowler recommended that instead of building this vessel the *Warreen* be assigned to Western Australia and that the two smaller vessels take her place in south-eastern Australia to fish intensively in restricted areas for tuna and other species. They would demonstrate whether or not tuna could be trolled in commercial quantities with reasonable consistency over a period. If these craft were not ready in time, he advocated that a Tasmanian tuna fishing boat, the *Weerutta,* be chartered to fish intensively in the Flinders Island and north-east Tasmanian areas from about February to July following (namely, in 1941).

The proposed small research vessels were not built, and Dr. Thompson recommended to the Chief Executive Officer that the *Weerutta* be chartered for nine months for tuna and barracouta

* An officer of the Division of Fisheries.

fishing in New South Wales and Tasmania. Approval of the tests was not obtained to take advantage of the current tuna season in New South Wales, but arrangements were completed for the carrying out of the test with two vessels in Tasmania from March to June, 1941. The tests were later extended to the New South Wales coast during mid-August to the end of November, 1941.

The tests themselves were organized by Mr. Fowler, and in place of outright chartering the two vessels concerned were subsidized by the C.S.I.R. In general, the agreement with the owner-skippers provided for the guaranteeing of each vessel for a £500 catch during a four months' fishing period, to cover the main tuna season in particular areas. The amount of the guarantee was stipulated by each owner as a condition of his agreeing to engage in the tests, and was based on his estimate of the costs of operation, plus reasonable remuneration. The owners bore all risks in respect of vessels, gear, and personnel. The contract set out that "the primary object of the test is the capture of tuna and barracouta with most importance attaching to tuna. If, however, conditions at any time are not suitable for the capture of these species, such opportunities as might be presented for the capture of other marketable species shall be seized, and the value of such catches shall be included in the total catch for which the guarantee is offered." It was arranged that the M.V. *Warreen* should continuously patrol the fishing area during the period of the tests for the information of the vessels participating, and that any fish caught by her should be disposed of to make up any payments that might have to be made under the terms of the guarantee.

The vessels selected for the test were two 55-ft. Tasmanian power ketches, the *Weerutta* and the *Jean Nichols*. The *Jean Nichols* was a new vessel, but the *Weerutta* had been converted for tuna trolling in 1939, and had fished during the Tasmanian seasons of 1939 and 1940.

Two separate tests were arranged. The first was in the east Tasmanian area, from Flinders Island to Cape Pillar, the *Weerutta* fishing from March to June and the *Jean Nichols* from mid-March to mid-July. The second test was made on the south coast of New South Wales from August to November inclusive, in which only the *Weerutta* participated. Both vessels used the same gear, of the pattern employed on the *Warreen* (C.S.I.R. Pamphlet No. 104), and trolled as a rule eight lines, at a speed of 8 knots. Bone jigs were mainly used for tuna fishing, but recourse was also had to wood jigs and feather lures.

General Results.

In both of the tests the vessels failed to reach their quotas under the guarantee, and in each instance ended the season with considerable deficiencies. In the Tasmanian test the *Weerutta* and the *Jean Nichols*, after allowing for the fish caught by the *Warreen*, showed a total deficiency of £380 8s. 9d. on the total guarantee of £1,000, and in the New South Wales test the loss was £383 0s. 6d. on a guarantee of £575 14s. 3d. Thus, the financial cost to the C.S.I.R. of the combined experiments was £763 9s. 3d. The detailed account of the fishing operations and assessment of the results will be described for the two areas separately.

2. The Tasmanian Test.

i. General.

The *Weerutta* operated mostly in the south-east Tasmanian region, principally in the vicinity of Cape Pillar, whilst the *Jean Nichols* was mostly fishing in the Furneaux Island region. Their respective performances were as follows:—

	Weerutta.		*Jean Nichols.*		*Warreen.*	
	Days.	Per cent.	Days.	Per cent.	Days.	Per cent.
Actual fishing days	69	57	67	56	76	80
Weatherbound	10	8	14	12	8	8
In port	37	30	26	22	11	12
Under repairs	6	5	12	10	—	—
	122 = 17·4 weeks.		119 = 17 weeks.		95 = 13·6 weeks.	

The *Weerutta* tried for tuna on 63 of the 69 fishing days, trolling for an aggregate of 410 hours, or 6·5 hours per day; the balance of the time was devoted to other types of fishing. The *Jean Nichols* tried for tuna on 47 days, and trolled for an aggregate of about 474 hours, or 10 hours per day; the balance of the fishing time was devoted to barracouta fishing. The *Warreen* tried for tuna on 71 days, trolling for an aggregate of 524 hours, or 7·4 hours per day.

In the following table of fish caught, the amounts transferred to the vessels at sea by the *Warreen* and included above under "General Results" have been deducted:—

Kind of Fish.	*Weerutta.*			*Jean Nichols.*		
	£	*s.*	*d.*	£	*s.*	*d.*
Tuna	124	7	6	80	5	5
Barracouta	90	16	0	126	8	3
Horse mackerel	33	14	9	—		
Salmon	10	14	5	—		
Various	19	1	2	—		
	278	13	10	206	13	8

ii. Economics.

The following analysis has been prepared of the working expenses and earnings of the two boats during the test:—

	Fishing Boat *Weerutta.*								
				From All Fish.			From Tuna Only.		
	£	*s.*	*d.*	£	*s.*	*d.*	£	*s.*	*d.*
Total earnings				278	13	10	124	7	6
Expenditure—									
Fuel oil	45	0	7						
Lubricating oil	4	16	0						
Ice	28	4	3						
New fishing gear	10	12	6						
Total expenditure				88	13	4	88	13	4
Net return for boat				190	0	6	35	14	2
Return for boat per week				10	18	5	—		
Return for boat per week if tuna only had been fished for				—			2	1	0

The approximate value of the fishing gear on the boat at the start of the test was £32. The crew comprised three men. Depreciation, insurance, and wages would be additional charges on boat earnings.

Fishing Boat *Jean Nichols.*

	£ s. d.	From All Fish. £ s. d.	From Tuna Only. £ s. d.
Total earnings		206 13 8	80 5 5
Expenditure—			
Fuel oil ..	75 18 8		
Lubricating oil	1 6 8		
Ice	8 0 0		
Fishing gear ..	10 0 0		
Total expenditure		95 5 4	95 5 4
Net return for boat		111 8 4	—
Return for boat per week		6 11 1	—
Net loss during period if tuna alone had been fished for		—	15 0 0

iii. The Tuna Catches.

Tuna were the primary objective of the tests, and most attention was paid to fishing for these species. The other fish taken were sought only incidentally, and when there were no tuna at the time. The following table is an analysis of the tuna fishing performances of the two boats compared with that of the *Warreen,* which was fishing in the same area for an equivalent period*:—

Species.	*Weerutta.* £ s. d.	*Jean Nichols.* £ s. d.	*Warreen.* £ s. d.
Bluefin ..	123 2 0	56 7 6	80 2 0
Striped tuna ..	0 14 6	26 8 0	59 4 6
Albacore ..	0 11 0	2 0 6	1 11 0
	124 7 6	84 16 0	140 17 6

* The slight differences between the values in this section and that in the preceding paragraphs are due to the fact that the data which follow are computed from the fishing boats' logs and the *Warreen* record sheets. Often numbers of fish only have been recorded by the boats, and the computed weights differ slightly from the cannery returns.

In quantities of fish, the details are as follows:—

Species.	*Weerutta.*		*Jean Nichols.*		*Warreen.*	
	No.	Weight.	No.	Weight.	No.	Weight.
		Tons.		Tons.		Tons.
Bluefin ..	603	4·924	251	2·215	363	3·204
Striped Tuna	9	0·029	325	1·056	729	2·369
Albacore ..	8	0·022	29	0·081	22	0·062
		4·975		3·352		5·635

To meet the guarantee of £500 per boat would have required a weekly average catch of about 1¼ ton. In actual fact, the catch of the *Weerutta* represented a weekly average of 0·29 ton, and that of the *Jean Nichols* of 0·20 ton. In the former case it was only 23 per cent. of the required quota, and in the latter only 16 per cent. The *Weerutta* had been fishing for tuna for six weeks before the tests officially started, but the amount caught during that period would not have affected the position materially. For the entire season the weekly average catch (for bluefin) was only 0·27 ton.

The difference in the catches of bluefin and striped tuna are due to the fact that striped tuna were confined to the Flinders Island and north-east Tasmanian region, where the *Jean Nichols* was mainly fishing, while the bluefin were more abundant in south-east Tasmania, where the *Weerutta* operated. The *Warreen* worked in both areas. The higher catch of the *Warreen* in striped tuna over that of the *Jean Nichols* may be partly accounted for in that the latter vessel began fishing just after the peak of the striped tuna concentration.

The frequency with which the various daily catches of bluefin were made by the *Weerutta* is given on p. 146.

iv. Interpretation of the Tests.

(i) *Southern Bluefin Tuna* (Thunnus maccoyii).

The value of the tests in assessing the tuna trolling possibilities of the Tasmanian region may be set in a better perspective by a consideration of other data possessed by the Division. This has been gained from two sources: (1) the sampling of the *Warreen*, and (2) the commercial fishing of the *Weerutta* during the 1939 and 1940 and part of the 1942 seasons.

(*a*) *The "Warreen's" sampling.*—Since May, 1938, the *Warreen* has trolled at frequent intervals in the south-east Australian littoral region, and data have been accumulated since October of that year on a basis of catch per unit of gear. A general review of her trolling operations is now in course of preparation and, though it is not possible to give here a summary of the quantitative results as in the

case of the New South Wales coast (see p. 148), it may be stated definitely that, during the period of the surveys and over the areas covered, the *Warreen* had recorded generally higher catch per unit of gear figures in New South Wales waters than in Tasmanian. Further, in the Tasmanian region itself, the figures are higher for south-east Tasmania, around Cape Pillar, than they are for the Flinders Island region.

(*b*) *The commercial fishing results.*—For this information we have as the only extant source the tuna trolling ventures of the ketch *Weerutta,* carried on since 1939 in south-east Tasmania.

In 1939, the *Weerutta* started fishing for tuna on May 9 and discontinued on August 4. During these three months, the boat caught 6·7 tons of tuna, which at £25 per ton was valued at £168. In 1940, fishing was begun on February 26 and ended on August 2, when the tuna took off. In this period, of just over five months, the boat caught 7·37 tons of tuna, valued at £184. In 1942, the year following the tests, the *Weerutta* endeavoured to resume tuna fishing at the start of the season, but the results were so disappointing that the venture was abandoned and her activities were diverted to other types of fishing. The tuna catch in all these years was almost entirely of southern bluefin.

It is rather difficult to reduce the preceding catch figures to a uniform basis for direct comparison. The varying length of the season with a varying abundance of fish precludes the use of a direct *pro rata* comparison. It was decided, therefore, to take a four months' period, covering the main part of the season, as a base. The figures for 1940 were reduced by eliminating the first and last half-months of the catches, whilst for 1939 an approximation of a four months' catch was arrived at by building up the earlier part of the season by following the trend of the catch curve. It was considered also that a fairer assessment of the real position in 1941 would be to take the four months' period as covering the months February to May, instead of the official test period of March to July.

The amended figures thus arrived at for a four months' season are as follows:—

	1939.	1940.	1941.
Quantity caught ..	7·9 tons.	6·7 tons.	6·3 tons.
Value	£198.	£168.	£158.

The three years' catches, therefore, do not vary very widely, and, despite the cumulative experience of the *Weerutta* and the improvement of her working conditions, a decline is shown in catches as compared with 1939. This fall is partly explained by the biological work of the *Warreen* in these waters and the study of the *Weerutta's* own catches during the period.

This is not the place to give a detailed analysis of these data, which will be reported in full in due course. A brief summary will suffice, however, to indicate the nature of the fluctuations which have been met with during the period of study.

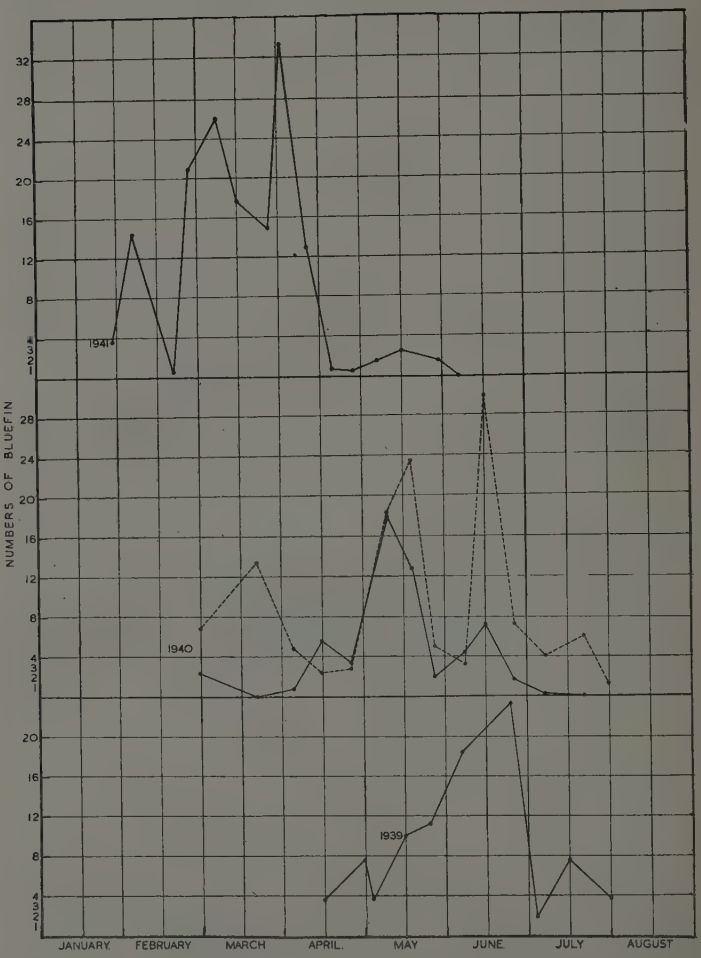

Fig. 1.—Operations of the ketch *Weerutta*.

Catch per day's absence—

——— three-year-old fish,

--------- two-year-old fish.

Fig. 1 gives an analysis of the catches of the *Weerutta* for each of the three seasons on a basis of catch per unit of effort, with the fish caught divided into size (age) groups. This shows the quite striking differences in the duration of the seasons as well as the differences in size or age composition. The season 1940 differs from 1939 and 1941 in that two groups of tuna were present, whereas only one (the larger) occurred in the last-mentioned years. The group on which the fishery fundamentally depends is the three-year-old group during the latter part of its growing season; in 1940 it was reinforced by the two-year-old group.* It will be seen also that the peak of the fishing season has progressively advanced during the three years, and in 1939 the whole of the catch was made in the months *after* the fish had taken off in 1941. As has previously been stated, the *Weerutta* was fishing from January 21, six weeks prior to the start of the official test. Her whole catch during the entire fishing period totalled 811 bluefin, the following being the monthly summaries:—

Month.	*Monthly Totals.*		*Cumulative Totals.*	
		Per cent.		Per cent.
January ..	40 Bluefin	4·9	40 Bluefin	4·9
February ..	167 Bluefin	20·6	207 Bluefin	25·5
March ..	382 Bluefin	47·1	589 Bluefin	72·6
April ..	185 Bluefin	22·8	774 Bluefin	95·4
May ..	36 Bluefin	4·4	810 Bluefin	99·8
June ..	1 Bluefin	0·1	811 Bluefin	99·9

Thus it will be seen that almost three-quarters of the fish were taken before the end of March, and practically the whole by the end of April. However, even if the tests had begun on January 21 the tuna results would not have been materially different. The weekly average for the four months' period beginning on that date is only 0·36 ton or 29 per cent of the 1·25 tons which had been reckoned on. The weekly average for the entire season during which fishing had been conducted, namely, 23·4 weeks, was only 0·27 ton.

An important cause of the weight variations in the total catch is not brought out in Fig. 1. This concerns the differences in the average weight of the size-groups from year to year. One of the striking features of the tuna work in 1940 was the demonstration that the two-year-old fish had suffered a serious retardation in growth rate during the growing period of 1939-40, though they entered the fishery at the usual size of this group. This meant that instead of the three-year-old fish averaging about 25½ lb. per fish during the autumn fishery in Tasmania (i.e., at the end of their growing season), as they did in 1939, the fish caught by the *Weerutta* in 1941 averaged only 18¼ lb. Had the three-year-old fish weighed as much as they did in 1939, the *Weerutta's* catch of bluefin during the test would have weighed 6·9 tons instead of 4·9 tons, and the total earnings of the boat would have been £173 instead of the £123 she actually did earn from bluefin tuna by her own fishing efforts. The year 1940 was inferior to 1939 because the larger three-year-old group was not so abundant, thus depressing the average weight of individual fish caught.

* See Serventy (1941).—The Australian Tunas. Coun. Sci. Ind. Res. (Aust.), Pamph. No. 104, p. 29, for a summary of the growth rates in the southern bluefin and the movement of the various age groups.

In actual numbers of fish landed by the *Weerutta,* the following are details of the three seasons under discussion (the total for 1941 is given, not merely for the test period):—

Year.	Season.	Two-year-old.	Three-year-old.	Total.	Av. Wt. per Fish
1939	3 months	0	587	587	25½ lb.
1940	5 ,,	710	308	1,018	16¼ lb.
1941	5 ,,	0	811	811	18¼ lb.

On a four months' basis, reducing the figures in the manner previously stated, the numbers of three-year-old bluefin caught by the *Weerutta* are as follows:—

1939 .. .. 689 individuals.
1940 .. .. 294 individuals.
1941 .. .. 770 individuals.

(*c*) *Conclusion.*—The available evidence shows that trolling for tuna in Tasmania by present methods is not a commercial proposition taken on its own, but it may be important as an adjunct to other types of fishing, particularly in "good" tuna years. Whether the present low catches are capable of increase by changes in the technique of trolling, greater experience, &c., of the fishermen are matters for the future. It is evident, however, and this aspect is further elaborated later in the New South Wales section of this report, that sharp fluctuations occur in the character of the bluefin stocks, and these must be seriously reckoned with in any local fishery. Some of the factors may cancel each other out in any one year, but their existence is a warning that the returns for the same amount of effort may vary sharply in different years.

(ii) *Striped Tuna* (Katsuwonus pelamis).

The season under review was a good one for striped tuna, according to the experience of the *Warreen.* Very extensive shoals were met with over long periods. Because on an average only about one fish in ten which was hooked by the vessel was actually landed (owing to the weakness of the jaws) trolling is too wasteful, at least when employing the present methods and technique, to warrant a continuance of commercial trolling for this species. There are, however, decided prospects for live-bait fishing.

(iii) *Albacore* (Thunnus germo).

All the experience of the Division suggests that this is a comparatively scarce species in inshore waters where present-day trolling operations are conducted. In 1938 they appeared to be more plentiful than in subsequent years. However, it may be ruled out of consideration for trolling ventures as now conducted.

3. The New South Wales Test.

i. General.

The extension of the guaranteed commercial tests to New South Wales was done on the recommendation of the Fisheries Advisory Committee of the C.S.I.R. at its meeting on June 12, 1941, and concurred in by Mr. Fowler. One of the Tasmanian boats, the *Weerutta,* was engaged on similar terms to those of the preceding

test. The period chosen from mid-August to the end of November, 1941, covered the main part of the southern bluefin season in New South Wales. A summary of the vessel's performance is as follows:—

	Days.	Per cent.
Actual fishing days	63	67
Weatherbound	21	22
In port	10	11
	94 days = 13·4 weeks.	

All these 63 fishing days were devoted to tuna fishing (there were exactly the same number of tuna-fishing days in the Tasmanian test).

The fish caught were as follows:—

Kind of Fish.	Number.	Weight (in tons).
Southern bluefin ..	1,042	7·845
Striped tuna ..	2	0·004
Albacore	18	0·095
Bonito	193	0·462
Total weight of tuna ..		8·406
Kingfish (*Seriola*) ..	25	0·124
Total weight of trolled fish ..		8·530

The total weight credited to the vessel at the cannery was 7·583 tons of tuna and 0·124 ton of kingfish. All were paid for on the basis of £25 per ton, namely, a total of £192 13s. 9d. The discrepancy of 0·823 ton is due partly to the loss of some bluefin whilst crossing the bar at Narooma, and the rejection by the cannery of approximately 928 lb. of bonito. In the calculations concerning tuna productivity, the economics of which follow, cognizance is taken of the whole original catch and not of the net cannery figures.

ii. Economics.

The following is an analysis of working expenses and earnings during the test:—

	£	s.	d.	£	s.	d.
Gross earnings (from tuna only)				210	3	0
Expenditure—						
Fuel oil	49	14	7			
Lubricating oil ..	7	15	0			
Ice (12 tons 8 cwt.) ..	36	17	9			
New fishing gear ..	7	12	6			
Total expenditure				101	19	10
Net return for boat (for 13·4 weeks) ..				108	3	2
Return to boat per week				8	1	5

iii. The Tuna Catches.

The catch of southern bluefin during the period averaged 0·585 ton per week, compared with 0·29 ton by the same vessel in the earlier Tasmanian test. The average catch per fishing day was 278·9 lb. in N.S.W. and 177·9 lb. in Tasmania, a ratio of 1·6 : 1. For total tuna, the average weekly catch in N.S.W. was 0·627 ton. Bluefin, as has been pointed out, was virtually the only species caught in Tasmania by the *Weerutta.*

The following table shows the frequency with which various daily catches were made by the *Weerutta,* both in New South Wales and Tasmanian tests:—

No. of Bluefin Caught per Day.	Number of Days. N.S.W.	Tasmania.
No fish	19	26
1– 10	26	18
11– 20	5	8
21– 30	3	5
31– 40	0	3
41– 50	3	1
51– 60	0	0
61– 70	1	2
71– 80	3	0
81– 90	0	0
91–100	1	0
101–110	0	0
111–120	0	0
121–130	1	0
131–140	0	0
141–150	1	0
	63	63

iv. Interpretation of the Test.

Though no commercial trolling of any moment similar to that of the *Weerutta* in Tasmania has been conducted in New South Wales, the surveys of the *Warreen* lend themselves better to analysis than those further south. The significance of the test and its value in assessing the productivity of bluefin in New South Wales can be discussed on somewhat different lines, therefore, from those employed in the Tasmanian tests.

The following paragraphs, extracted from the report of the 22nd cruise of the *Warreen,* give an indication of the characteristics of the season:—"According to the catch per unit of gear figures of the *Warreen,* the present season (1941) is a very poor one, and is only about half as good as the peak season of 1939. The predominant age-group, the third-year fish, averaged about 17 lb. (i.e., at the beginning of the growing season) and was thus normal in size, compared with last year. Striking features of this year's age-composition of the bluefin stocks were the dearth of large four-year-old fish, and also of the small two-year-old class. This was the case last year as well. Another noteworthy feature was that this year the

bluefin did not penetrate much further north than the Montague Island region, whereas in 1939 they reached Sydney. For the first time since the Division's investigations began there was no tuna fishing at Jervis bay."

The use of the standard trolling gear by the *Warreen* on the New South Wales coast during 1938, 1939, 1940, and 1941, when it was operated in a fairly consistent manner throughout, enables the computation of index numbers for each season to give a numerical expression of the varying abundance of the bluefin.

As the average weight of the fish caught varies widely each season, for commercial purposes the numerical index must be weighted to take account of this factor.

By themselves, of course, the index numbers obtained by the *Warreen* cannot be directly applied commercially except insofar as they reveal the fluctuation which exists from year to year. In the season of the test, however, by utilizing the data obtained from the operation of the *Weerutta,* the catches of the two vessels could be linked. By interpolation the index numbers of the *Warreen* for the earlier years can then be given a direct commercial interpretation.

In the following table the column " commercial index " refers to the numerical index as weighted to take account of the average weight of the fish for the season. The commercial values are computed from the *Weerutta's* gross earnings for the test season, reckoned at £25 per ton. The year 1939 was selected as the base year, with the index at 100:—

Year.	Numerical Index.	Mean Wt. of All Fish.	Commercial Index.	Av. Expected Catch per Week.	
				Av. Tons.	Av. Value.
		lb.			
1938	45	10·27	29	0·414	£10 7 0
1939	100	16·16	100	1·427	35 13 6
1940	81	12·39	62	0·885	22 2 6
1941	42	15·75	41	0·585	14 12 6

It will be seen that the season 1939 was by far the best of the four which had been investigated, and it may be fairly said that of these four seasons only one, that of 1939, offered a reasonably attractive return to troll fishermen.

The *Warreen* passed out of the control of the C.S.I.R. to the Royal Australian Navy in 1942, and no effective means remained of checking on the tuna stocks. From the experience of fishermen and other evidence, however, it was clear that the 1942 season was a very poor one. The 1943 season showed a pronounced recovery, and southern bluefin was abundant during the last part of the season. Such evidence as was available indicated that the 1944 and 1945 seasons were also better than the test season of 1941.

The results show that, with the methods used, trolling for southern bluefin on the New South Wales coast can only be regarded as a border-line fishery, suited to the operations of small boats with low overhead costs. The matter is entirely one of economics, however, and were the Californian scale of prices ruling a much brighter position would be shown. On Californian standards, the southern bluefin is under-valued locally, and in the following table the computed values of the New South Wales catch are compared with equivalent Californian figures (at £32 per ton, *vide* "The Australian Tunas," C.S.I.R. Pamphlet 104, p. 11):—

Year.	Average Return per Week (Bluefin only).	
	@ Ruling N.S.W. Rates.	@ Californian Rates.
1938	£10 7 0	£13 4 11
1939	35 13 6	45 13 3
1940	22 2 6	28 6 5
1941	14 12 6	18 14 5
Average Weekly return for the season (Aug-Nov.)	26 13 11	26 9 9

As an approximate check on the validity of the method of assessment, it is of interest to compare the tuna production figures for the Merimbula district kept by Mr. W. L. Packenham, the local fishery inspector, since 1937. Unfortunately, no similar data are available for other districts.

The amount of bluefin caught is as follows:—

	Year—				
	1937.	1938.	1939.	1940.	1941.
Boxes ..	148	4	542	38	125

Prior to 1940 only the Melbourne bait market was available to these fishermen. In 1940 the Eden cannery came into the market for tuna, and could be regarded as providing an added stimulus to tuna fishing. In 1941 the Narooma cannery entered into general production and was prepared to take all the tuna offering. The figures clearly show that 1939 was an outstanding year, but they probably exaggerate its superiority over other years, as in the good year when fish are plentiful everybody is out after them. In poor years the tuna are mostly left alone and effort is concentrated on other species.

Some further remarks may be made on the index figures. The years 1938 and 1941 were incompletely sampled as compared with the other seasons, but are comparable with each other. The low average weight of fish in 1938 is due to the predominance in that year of the smallest size-group of tuna, though it is likely the average would have

been raised slightly had the earlier part of the season been better sampled. In 1941 there was a noteworthy scarcity of these small fish. The index numbers themselves should be regarded as approximate; they were prepared on a system which took account of the shrinking of the tuna area as the season advanced, and this required some arbitrary adjustment of the figures. However, each year was treated in a comparable manner and, therefore, their relative values may be accepted as approximating reasonably near to the real situation. Fuller details will be given when the trolling results of the *Warreen* during her surveys in south-eastern Australia are published.

Appendix.

Weather Conditions—Tasmanian Area.

The Director of Meteorological Services (Group-Captain H. N. Warren) has provided the following data on the weather conditions in the area under test:—

"It has not been possible to arrive at more than a very general estimate of how wind and sea conditions varied from normal in the period March 1 to June 30, 1941. Statistical records of wind and sea conditions have not been tabulated in the past.

From an inspection of mean and normal pressure gradient maps, which show differences in air pressure between various stations on which wind force depends, the following notes have been prepared, which give a general indication of the characteristics of these months:—

March: *Flinders Island Area.*—The pressure gradient indicated winds above average strength or frequency from a westerly direction. A period of exceptionally low pressure was experienced from March 20–28.

East Coast of Tasmania.—Ditto—but winds more from south-west or south than normally.

April: *Flinders Island Area.*—Winds rather above the average, easterly tendency, but on the whole a quieter month than normally.

East Coast of Tasmania.—Average or slightly over average winds, with a south-west or southerly tendency.

May: *Flinders Island Area.*—The gradient indicated rather higher wind strength than normal from west or south-west, or a higher frequency of winds from this direction.

East Coast of Tasmania.—Ditto—though Tasman Island report showed a prevalence of north-westerlies, strength would be considerably higher than normal.

June: *Flinders Island Area.*—Somewhat stronger winds than normal from west.

East Coast of Tasmania.—Under average wind strength from west or south-west.

The state of sea would naturally correspond to strength of the wind and whether the latter were onshore or offshore. The normal gradient is for west or south-west winds over this area."

Summary.—The general trend indicated by the pressure charts during the period covered by the inquiry could be stated as somewhat rougher conditions than normal, but not markedly abnormal.

WEATHER CONDITIONS—NEW SOUTH WALES AREA.

The Director of Meteorological Services has supplied the following data on weather conditions in the area under test:—

"I regret that very little information is available concerning wind and sea conditions compared with normal between Tuross Inlet and Cape Howe during the period August to November inclusive, 1941.

We have an anemometer at Moruya Heads, and mean daily wind speeds for each of the four months were as follows:—

August—7·8 m.p.h. (0·7 m.p.h. below the average).

September—9·2 m.p.h. (0·2 m.p.h. above the average).

October—9·8 m.p.h. (0·7 m.p.h. above the average).

November—8·2 m.p.h. (22 days) (0·9 m.p.h. below the average).

Wind directions at Moruya were:—

August.—Mainly S. to S.W., strong on 2 days.

September.—Mainly S.W. in the morning, N.W. or N.E. in the afternoon, strong on 4 days.

October.—Mainly S.E. to S.W. in the morning and E. to S. in the afternoon, but a fair percentage of N.E., strong on 5 days.

November.—Mainly N.E. to S.E., strong on 3 days.

At Gabo Island winds were as follows:—

August.—Majority W. to S.W., strong to gales on 9 days.

September.—Majority N.W. to S.W., strong on 4 days.

October.—Mainly W. to S.W., strong or gales on 15 days.

November.—Mainly W. to S.W., strong on 11 days.

On the whole the season appears to have been about an average one. Mean pressure was above the average in August and November, and below the average in September and October."

NOTES

The Utilization of German Technologists and Scientists in Australia

The Minister for Post-War Reconstruction (Hon. John J. Dedman) has announced that a scheme, appertaining to reparations, has been approved by Federal Cabinet, which should be of interest to Australian industrialists and research institutions. Under this scheme it is proposed to bring into Australia, under certain safeguards, scientists and technologists from Germany. The Australian scheme will be similar to the plans adopted by the United Kingdom, U.S.A., and France, which are already operating for the acquisition of further knowledge of the latest scientific developments that have taken place in Germany.

Technical experts who are required, and who volunteer to come to Australia, will, if politically acceptable, enter Australia for a definite period under contract to the Commonwealth Government. They will be subject to supervision and will have the normal social service and taxation responsibilities of residents. In all cases, these skilled men will be employed only if no Australian, or United Kingdom citizen who is available to migrate here, has the necessary skill and knowledge for that particular sphere of endeavour.

With the introduction of these proposals it is hoped that new industries may be developed here and that existing ones will benefit appreciably from the overseas experience that will be made available to them. For example, in some branches of pure research, metallurgy, electronics, utilization of brown coal, the chemical industry, the production of aluminium, German knowledge far outstrips our own, and Australian industry is now in the position to acquire valuable working information from outstanding German specialists. The services of specialists brought out under Commonwealth Government sponsorship will be available to State authorities and interested private firms who apply for these men.

A Committee which has been set up will consider the requirements of Australia, the qualifications of all German specialists for whom application is made or who may apply, and will advise the Secondary Industries Division of the Department of Post-War Reconstruction—which will be the administrative authority in Australia—as to the suitability of suggested scientists and technologists. This Committee is broadly constituted, having a representative each from the Associated Chamber of Manufactures, Combined Australian Universities, the Commonwealth Office of Education, the Council for Scientific and Industrial Research, the Australian Council of Trade Unions, the Department of Immigration, and the Secondary Industries Division.

The Secondary Industries Division will welcome any inquiries from Australian firms for suitable personnel where it is believed that the introduction of such men could make a contribution to the development of Australian secondary industries. The Commonwealth Government is anxious to make such specialized knowledge available to those who can best use it and so derive the maximum benefit for Australia.

Catalogue of Scientific and Technical Periodicals, New Edition

The following list is supplementary to those published in previous issues. Libraries possessing items with which they are not credited are requested to forward missing entries showing holdings, to Mr. E. R. Pitt, care of C.S.I.R. Information Service, 425 St. Kilda-road, Melbourne, S.C.2, for inclusion in the Catalogue. As full information as possible is given, and bibliographical accuracy cannot be guaranteed. Later particulars are given of a few periodicals included in former lists.

NEW SCIENTIFIC AND TECHNICAL PERIODICALS.

Aero review. Rochester, *N.Y.* V.1, No. 1 = Feb., 1946. *Monthly.* 25c., $3·00.

Agricultural chemicals. New York. *Monthly.*

American aquarist. V.1, No. 1 = Feb., 1946. *Monthly.* 25c., $2·50.

American journal of medicine. New York. V.1, No. 1 = July, 1946. *Monthly.* $10·00.

American medical women's association. Journal. Nashville. V.1, No. 1 = Apr., 1946. *Monthly.* 35c., $3·00.

Atom. Denver, *Col.* V.1, No. 1 = Fall, 1945. *Quarterly.* 25c., $1·00.

Atomic age. Sea Cliff, *N.Y.* V.1, No. 1 = Jan., 1946. $1·00. [Changed to $2·00 with V.1, No. 3, Mar., 1946.]

Atomic engineering. New York. V.1, No. 1 = Sept., 1945. *Irreg.* 25c. per copy (processed).

Atomic information. (National committee on atomic information.) Washington, *D.C. Monthly.*

Atomic scientists of Chicago. Bulletin of the atomic scientists. *Semi-monthly.* (N.CSIR:SR; V.CSIR:HO.)

Ceramic association of New York. Monthly news letter. Albany, *New York. Monthly.*

Coal technology. New York. V.1, No. 1 = Feb., 1946. *Bi-monthly.* $1·50, $6·00.

Corrosion and material protection. Pittsburgh, *Pa. Monthly.*

Diesel journal. Jersey City, *N.J.* V.1, No. 1 = Jan., 1946. *Monthly.* 35c., $3·00.

Duodecimal bulletin. (Duodecimal society of America.) Staten Island, *N.Y. Irreg.*

Engineer and foundryman. Johannesburg. *Monthly.*

Fonderie. (Association technique de fonderie.) Paris. *Monthly.*

Food freezing. New York. V.1, No. 1 = Nov., 1945. *Monthly.* 35c., $4·00.

Frozen food industry and locker plant journal. New York. V.1, No. 1 = Nov., 1945. *Monthly.* 50c., $3·00.

Frozen food merchandising. New York. V.1, No. 1 = Mar., 1946. *Monthly.* $3·00.

Fur and feather magazine. (National fur and feather association.) Sliema, *Malta. Quarterly.*

Geriatrics. Minneapolis, *Minn.* V.1, No. 1 = Jan.-Feb., 1946. *Bi-monthly.* 50c., $3·00.

Industrial diamond review. London. *Monthly.*

Journal of the history of medicine and allied sciences. New York. V.1, No. 1 = Jan., 1946. *Quarterly.* $2·50, $7·50. (N.SPH.)

Lubrication engineering. Chicago. V.1, No. 1 = June, 1945. *Quarterly.* 75c., $3·00.

Mining and metallurgical society of America. News letter.

Navigation. (Institute of navigation.) Los Angeles, *Cal. Quarterly.*

Occupational medicine. Chicago. V.1, No. 1 = Jan., 1946. $6·00. (N.PHD, SPH.)

Overseas watchmaker, jeweller and silversmith. London. *Bi-monthly.*

Petroleum news notes. (American petroleum institute.) New York. *Monthly.*

Photographic age. New York. V.1, No. 1 = July, 1946. *Monthly.* $4·00.

Plastics trends. (Plastics industries technical institute. *Research division.*) Los Angeles, *Cal. Monthly.*

Quarterly review of urology. Washington, *D.C.* V.1, No. 1 = Mar., 1946. *Quarterly.* $9·00.

Radio maintenance. New York. *Monthly.*

Refrigeration abstracts. New York. V.1, No. 1 = Jan., 1946. *Quarterly.* $1·50, $7·00. (V.EIC.)

Reinforced concrete review. (Reinforced concrete association.) London. *Semi-annual.*

Science illustrated. New York. V.1, No. 1 = Apr., 1946. *Monthly.* $3·00.

Sight. Pittsburgh, *Pa.* V.1, No. 1 = Apr., 1946. *Monthly.* 10c., $1·00.

Southern refrigeration journal. Memphis, *Tenn. Monthly.*

Telectronic news. (Television film industries corp.) New York. *Monthly.*

Television showman. New York. *Bi-weekly.*

Reviews

"The Use of Heterosis in the Production of Agricultural and Horticultural Crops," by T. Ashton.

(Imperial Bureau of Plant Breeding and Genetics, 1946, pp. 30 Price 3s. (stg.). Obtainable from the Imperial Agricultural Bureaux, Agricultural Research Building, Penglais, Aberystwyth, Wales.)

This bulletin brings together summaries of a large number of papers which have a bearing on the possibilities of commercial exploitation of hybrid vigour in agricultural and horticultural crops. There are four main sections to the bulletin dealing, respectively, with heterosis in self-pollinated, cross-pollinated, and asexually propagated plants and in forest trees. Within these four sections each crop is treated individually. In the case of maize, only papers on certain fundamental problems are included.

There is an increasing indication that the systematic use of heterosis in commercial crop production offers important possibilities in other crops besides maize, where hybrid production is now an established and well-known practice in the United States. Though the cross-pollinated species are the most promising, the self-pollinated also appear to offer definite prospects, especially those in which a large number of seeds is produced from a single flower, hybridization is a relatively easy process, and the plants are widely spaced in cultivation. These include tobacco, tomato, and egg plant. The value of heterosis is more limited in the case of the normally self-fertilized plants in which one flower produces only one seed and artificial hybridization is a difficult operation, as in the case of wheat, oats, barley, sorghum, and rice.

The bulletin concludes with a useful bibliography of 234 references.

W.I.

"HINTS TO PROSPECTORS AND OWNERS OF TREATMENT PLANTS," edited by H. A. Corbet.

(Issued by the Royal Mint, Perth, Western Australia, 1946, pp. 80. Price 1s. Obtainable from Government Printer, Perth, Mining Registrars throughout W.A., and other sources.)

This publication was brought out by the Royal Mint, Perth, for the benefit of men in isolated mining ventures. It includes useful hints on prospecting, dry blowing, miners' rights and regulations, geology, batteries and cyaniding, preparation of samples for assaying, use of explosives, first aid and health; reference is also made to prospecting for other economic minerals. For this reason, while details relate more specifically to the Western Australian goldfields, the booklet has a much wider appeal to all those who propose prospecting or are engaged in the goldmining industry in remote regions where limited facilities and difficult conditions pertain.

The practical value of the booklet may be gauged from the fact that it has now reached the 9th edition, this issue following closely on the 8th edition which appeared only early this year.

Forthcoming Publications of the Council.

At the present time, the following future publications of the Council are in the press:—

Bulletin No. 200.—"Preparation of Core Ingredients for Searchlight Carbons," by T. R. Scott, M.Sc., B.Ed.

Bulletin No. 201.—"Grazing Management: Continuous and Rotational Grazing by Merino Sheep. 1. Study of the Production of a Sown Pasture in the Australian Capital Territory under Three Systems of Grazing Management," by R. M. Moore, B.Sc.Agr., Nancy Barrie, B.Sc.Agr., and E. H. Kipps, B.Sc. *Appendix,* "The Measurement of Pasture Yield under Grazing," by G. A. McIntyre, B.Sc. "2. The Effect of Continuous and Rotational Grazing on the Infestation of Sheep with Internal Parasites," by H. McL. Gordon, B.V.Sc., and Helen Newton Turner, B.Arch. "3. Note on Pasture Management," by J. Griffiths Davies, B.Sc., Ph.D.

Bulletin No. 202.—"The Strain Complex and Symptom Variability of Tomato Spotted Wilt Virus," by D. O. Norris, M.Sc. (Agric.).

Bulletin No. 203.—"Agar in Australia," by E. J. Ferguson Wood, B.A., M.Sc.

Bulletin No. 204.—"A Soil Survey of Part of Waterhouse Estate, County of Dorset, North-East Coast, Tasmania," by G. D. Hubble, B.Agr.Sc.

Bulletin No. 205.—"Studies on the Breeding Performance of Ewes," by R. B. Kelley, D.V.Sc.

Bulletin No. 206.—"Pedogenesis Following the Dissection of Lateritic Regions in Southern Australia," by C. G. Stephens, M.Sc.

Bulletin No. 207.—"The Fumigation of Wheat in Bag Stacks," by Frank Wilson and F. J. Gay, B.Sc., D.I.C.

Bulletin No. 208.—"Surface Fumigation of Insect Infestations in Bulk-Wheat depots," by Frank Wilson and A. T. Mills.

Bulletin No. 209.—" Interaction of Surface Infestation, Temperature, and Moisture Content in Bulk-Depot Wheat," by Frank Wilson.

Bulletin No. 210.—" Preliminary Survey of the Natural Pastures of the New England District of New South Wales, and a General Discussion of Their Problems," by R. Roe, B.Sc. (Agric.).

Bulletin No. 211.—" The Water Retting of Flax," by W. L. Greenhill, M.E., Dip.Sc., and Jean F. Couchman, B.Sc.

Bulletin No. 212.—" The Frictional Properties of Lead-Base and Tin-Base Bearing Alloys: The Role of the Matrix and the Hard Particles," by D. Tabor, Ph.D.

Bulletin No. 213.—" Laboratory and Field Tests of Mosquito Repellents," by R. N. McCulloch, B.Sc., B.Sc.Agr., and D. F. Waterhouse, M.Sc.

Bulletin No. 214.—" The Preparation and Properties of Synthetic Cryolite," by P. Dixon, M.Sc., and T. R. Scott, M.Sc.

Bulletin No. 215.—" Studies in the Biology of the Skin and Fleece of Sheep. 4. The Hair Follicle Group and its Topographical Variations in the Skin of the Merino Foetus," by H. B. Carter, B.V.Sc., and Margaret H. Hardy, M.Sc.

Bulletin No. 216.—" An Examination of the Peet-Grady Method for the Evaluation of Household Fly Sprays," by D. F. Waterhouse, M.Sc.

Bulletin No. 217.—" The Relative Importance of Live Sheep and of Carrion as Breeding Grounds for the Australian Sheep Blowfly *Lucilia cuprina,*" by D. F. Waterhouse, M.Sc.

Bulletin No. 218.—" Studies of the Physiology and Toxicology of Blowflies. 12. The Toxicity of DDT as a Contact and Stomach Poison for Larvae of *Lucilia cuprina.* 13. Insectary Tests of Repellents for the Australian Sheep Blowfly," by D. F. Waterhouse, M.Sc.

Bulletin No. 219.—" Spray Tests against Adult Mosquitoes. 1. Laboratory Spray Tests with Culicine (*Culex fatigans*) Adults," by D. F. Waterhouse, M.Sc. " 2. Spray Tests with Anopheline (*Anopheles punctulatus farauti*) Adults," by D. F. Waterhouse, M.Sc., and D. O. Atherton, M.Sc.Agr.

Bulletin No. 220.—" The Preparation and Use of Harvey's Reduced Strychnine Reagent in Oceanographical Chemistry," by D. Rochford, B.Sc.

Bulletin No. 221.—" Contributions to the Study of the Cell Wall. 4. The Nature of Inter-Cellular Adhesion in Delignified Tissue. 5. The Occurrence, Structure, and Properties of Certain Cell Wall Deformations," by A. B. Wardrop, M.Sc., and H. E. Dadswell, D.Sc.

Bulletin No. 222.—" The Chaetognatha of South-Eastern Australia," by J. M. Thomson, M.Sc.

Bulletin No. 223.—" Report of Marine Borer Survey in New Guinea Waters," by A. W. Shillinglaw, B.Sc., Dip.For., and D. D. Moore, B.Sc., A.S.T.C.

Bulletin No. 224.—" Mechanical Composition of Soil in Relation to Field Descriptions of Texture," by T. J. Marshall, M.Agr.Sc., Ph.D.

Bulletin No. 225.—" Studies on the Control of Wheat Insects by Dusts. 1. Field Tests of Various Mineral Dusts against Grain Weevils," by F. J. Gay, B.Sc., D.I.C., F. N. Ratcliffe, B.A., and R. N. McCulloch, B.Sc., B.Sc.Agr. " 2. Further Tests of Various Mineral Dusts for the Control of Grain Pests," by F. J. Gay, B.Sc., D.I.C. " 3. The Use of Dust Barriers for the Control of Grain Insects," by F. J. Gay, B.Sc., D.I.C. " 4. The Use of DDT– and 666– impregnated Dusts for the Control of Grain Pests," by F. J. Gay, B.Sc., D.I.C.

" The Commercial Timbers of Australia—Their Properties and Uses," by I. H. Boas, M.Sc.

" Handbook of Australian Pelagic Tunicates," by Harold Thompson, M.A., D.Sc.

J. J. Gourley, Government Printer, Melbourne.

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